

An Introduction to Measuring Water Flow and Reporting Water Use for Large-Scale Stream-Diversion Ditches in Hawai‘i

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Methods described here follow U.S. Geological Survey (USGS) and International Organization for Standardization (ISO) protocol unless noted otherwise.



GOAL

The goal of this presentation is to provide an introduction to the why, where, what, and how of measuring water flow and reporting water use to the State of Hawai'i Commission on Water Resource Management.

What is Water Use?

Water use is water that is used for a specific purpose, such as for domestic use, irrigation, or industrial processing. Water use pertains to human's interaction with and influence on the hydrologic cycle, and includes elements, such as water withdrawal from surface and groundwater sources, water delivery to homes and businesses, consumptive use of water, water released from wastewater-treatment plants, water returned to the environment, and instream uses, such as using water to produce hydroelectric power.

Stream Water that is Diverted into Ditches

- For purposes of reporting to the State of Hawai'i Commission on Water Resource Management (CWRM), water use is the volume of water diverted from the stream at or near the point of diversion(s) into the ditch
- Water use is reported as the number of gallons diverted per month to CWRM
- The use of the diverted water should also be reported

Why Measure and Report Water Use?¹

- [Section 13-168-7 of the Hawai'i Administrative Rules](#) requires owners or operators of stream diversions to report their water use every month to the State of Hawai'i Commission on Water Resource Management (CWRM).
- Measuring and reporting water use will establish use history and need for water
- Accurate water-use information is essential to understanding water availability, distribution, and use trends.
- Continuous measurement of water use is required by CWRM for large-scale ditch systems.

¹Information provided by the [State of Hawai'i Commission on Water Resource Management](#) (CWRM).

Where Water Data are to be Collected for Reporting to the State of Hawai'i Commission on Water Resource Management¹

- CWRM documents the specific locations at which water use is measured.
- CWRM defines “point of diversion” as the place where water is removed from a stream channel.
- Monitoring section needs to be as close as practicable from point of diversion.
- With multiple points of diversion, a centralized measurement location may be approved by CWRM on a case-by-case basis.

¹Information provided by the [State of Hawai'i Commission on Water Resource Management](#) (CWRM).

Presentation Topics for Measuring Water Flow and Reporting Water Use

- Open-channel measurement methods
- Pipe-flow measurement methods
- Computing and reporting monthly water use



Open-Channel Flow Measurement Methods

- Selecting measurement sites
- Controls (weirs, flumes, other channel features)
- Measuring stage (water level, gage-height)
- Gage datum and gage-height at zero flow
- Measuring flow (discharge)
- Field inspection notes
- Converting stage readings to flow
- Index-velocity method for computing discharge

Open-channel flow measurement methods

Selecting Measurement Sites

- Easy and safe access
- Stable location in the ditch – no sloughing, eroding, or leaking
- Straight channel segment
- Free of aquatic vegetation
- Take advantage of existing structural features (controls) such as weirs and flumes

Open-channel flow measurement methods

Controls

Control definition: Physical feature(s) that define the relation between stage (water-level, gage-height) and flow (discharge)

- Control can be weirs, flumes, and other features
- Control must be stable; ditch sections prone to scour, fill, and growth of aquatic vegetation are undesirable
- Control must only allow for a single flow value for a given stage
- See [Rantz and others \(1982\)](#), vol. 1, chap. 3 for more information about controls

Open-channel flow measurement methods -- controls

Weirs – weir designs



← V-notch
(sharp crest)

Irregular →



← Rectangular
(sharp crest)

Broad-crest →



Advantages of weir controls

- Weirs are relatively inexpensive to install
- Flow rate is a function of head (water level above the weir crest) -- tables to convert water level to discharge are readily available (except for irregular shaped weirs)

Disadvantages of weir controls

- Weirs catch debris (especially V-notch style weirs) -- require frequent maintenance
- Weirs do not work well in sediment laden water because of sediment deposition behind weir -- require frequent maintenance
- Cannot be used on steep-gradient ditches because of inadequate ponding behind the weir
- Ditch banks must be high enough to accommodate backwater caused by weir

Weirs – other considerations

- Weir must be installed in a straight section of ditch so that flow entering the pool behind the weir has uniform velocity distribution
- Lengths of the straight sections upstream of the weir are dictated by the weir type
- Weir must be level if weir tables are used to determine flow
- No leakage under or around the weir
- Vegetation must be cleared to ensure weir is not submerged by backwater

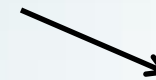
Open-channel flow measurement methods -- controls

Flumes – flume designs



← Parshall

H-flume



← Montana
(short Parshall)

Many, many other designs not shown

Advantages of flume controls

- Flow rate is a function of head (water level above the flume floor) -- tables to convert water level to discharge are readily available
- Create less backwater than weirs
- Can be designed for steep gradient or flat gradient ditches
- Can be used on ditches with low banks
- Work well in sediment-laden waters
- Self cleaning, less likely to trap debris (with the possible exception of some H flumes)

Disadvantages of flume controls

- Expensive - high design and installation cost if cast in place (Prefabricated flumes may be cheaper to install)
- Tricky to install

Flumes – other considerations

- Flume type must be matched to the ditch gradient
- Flumes must be installed in a straight section of ditch so that flow entering the flume has uniform velocity distribution
- Lengths of the straight sections above and below the flume are dictated by the flume type
- Vegetation must be cleared to ensure the flume exit is not submerged so the water has good getaway
- There should be no leaks in or around the flume
- See [Kilpatrick and Schneider \(1983\)](#), [Rantz and others \(1982, p. 12\)](#) for more information

Open-channel flow measurement methods -- controls

Other types of controls



Irregular weir
(natural or man-made)



Break in slope with
increase in gradient

Constriction



Advantages of these controls

- No installation costs -- using existing features
- May work well in sediment-laden waters
- May not trap debris

Disadvantages of these controls

- Require direct measurement of water-level and flow to develop relationship needed for stage-discharge rating (discussed later)
- May not work well in sediment-laden waters
- May trap debris

Other controls – considerations

- Need a control section that is straight, free of vegetation, not prone to sediment deposition, and have good sensitivity to flow changes
- Slight channel constrictions and/or breaks in slope (with slope increasing at the break) that are stable are desirable because they slow and back up flow, increasing the sensitivity to flow changes
- If no constrictions or slope breaks, find location where flow is tranquil and evenly distributed

Measuring Stage (water-level, gage-height)

- Stage data are used with weir, flume, or other rating equations to determine discharge.
- Stage is defined as elevation of the water surface above an established data plane such as sea level or an arbitrary data plane.
- Water-surface elevation for most ditches is measured above an arbitrary plane and is commonly referred to as gage height. Gage height and stage are used interchangeably in this presentation.
- Recommended measurement units: feet and hundredths of feet.
- Accurate gage-height measurement is required for determination of discharge whether you are using weir or flume equations or pairing gage height to direct discharge measurements.

Open-channel flow measurement methods

Measuring Stage – topics

- Staff gages and other non-recording reference gages
- Where to install relative to the control location
- Installation and operation of recording stage gages
- Datum determination

Measuring stage

Non-Recording Reference Gages

- Want a simple method to easily read water level
- Type of reference gage chosen depends on local site conditions
- Reference gage must be securely fastened so that it is stable and not easily moved or damaged
- See [Sauer and Turnipseed \(2010\)](#) for more information

Types of Non-Recording Reference Gages

Staff gages

- Commercially available, vertical staff gage consisting of a porcelain-enameled iron plate with graduations every 0.02 feet
- Gage-height is read directly from the staff gage
- Must cover expected range of stage



Measuring stage; non-recording reference gages

Tape-up reference point (RP) -- installed below the water surface

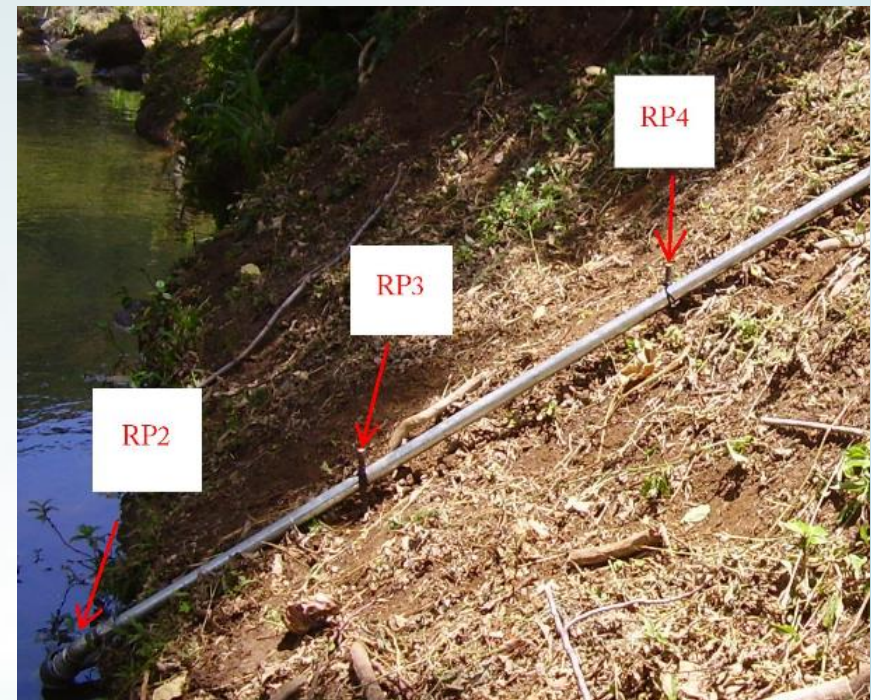
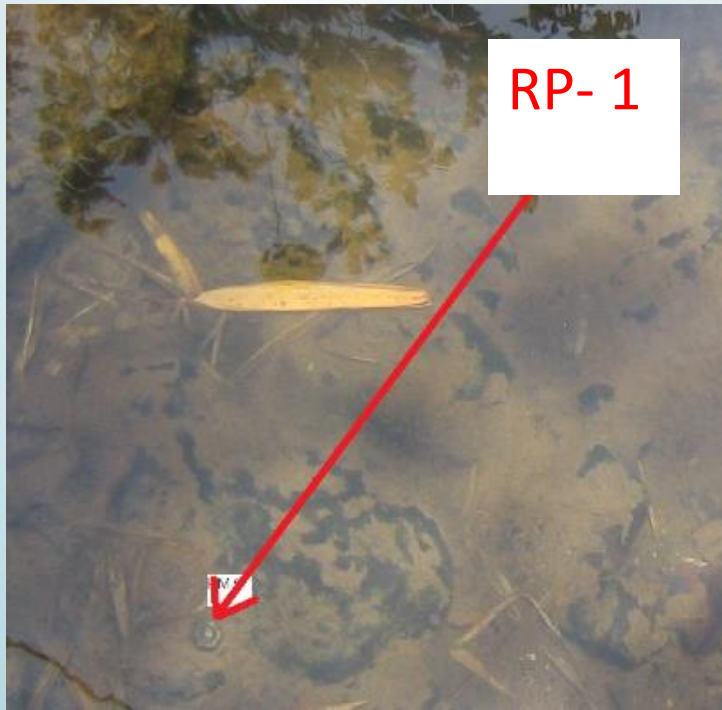
Gage-height =

(RP elevation) + (measured distance from RP to water surface)

- Tape-up reference points can be anchor bolts mounted to the bottom of a concrete-lined channel, or rebar or angle iron driven into the channel bottom.
- Use a folding pocket ruler or wading rod to measure distance from RP to water surface
- Advantages -- inexpensive, easy to install, and less prone to collect debris.
- Disadvantages -- hard to see in turbid water, not direct read of gage-height, and cannot be read at a distance.

Measuring stage; non-recording reference gages

Tape-up reference point (RP) – continued



Measuring stage; non-recording reference gages

Tape-down reference point (RP) -- installed above the water surface

Gage-height =

(RP elevation) – (measured distance from RP to water surface)

- Gage height can be measured from a fixed point directly above the water surface using a folding pocket tape to measure the distance from the reference point down to the water surface
- Tape-down reference points can be anchor bolts mounted to the side of a vertical ditch wall or on the side of a walkway spanning the ditch, or can be made of something sticking out over the water surface from the side of the ditch
- Advantages -- inexpensive, easy to install, out-of-the-water so they won't collect debris, not affected by turbid water
- Disadvantages -- require leaning out over the water, not direct read of gage-height, and cannot be read at a distance

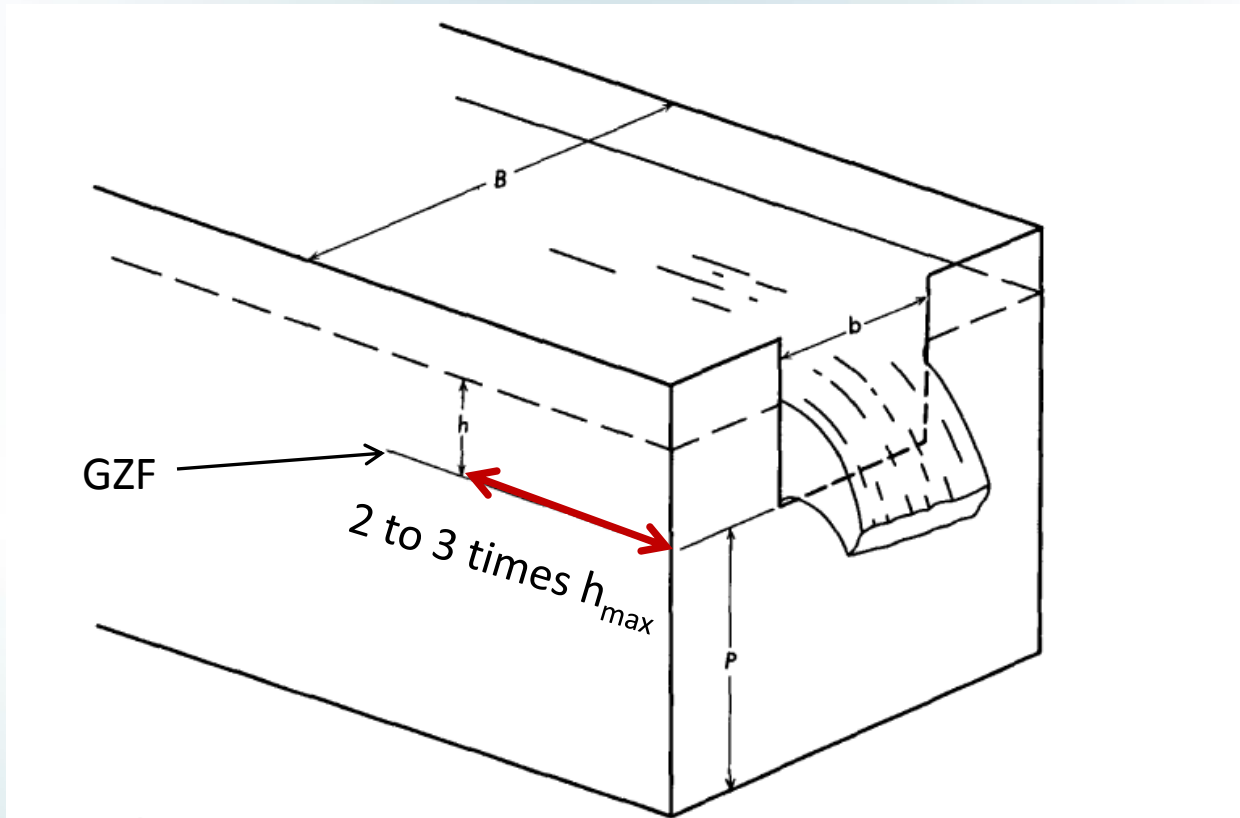
Measuring stage; non-recording reference gages

Tape-down reference point (RP) – continued



Measuring stage; non-recording reference gages

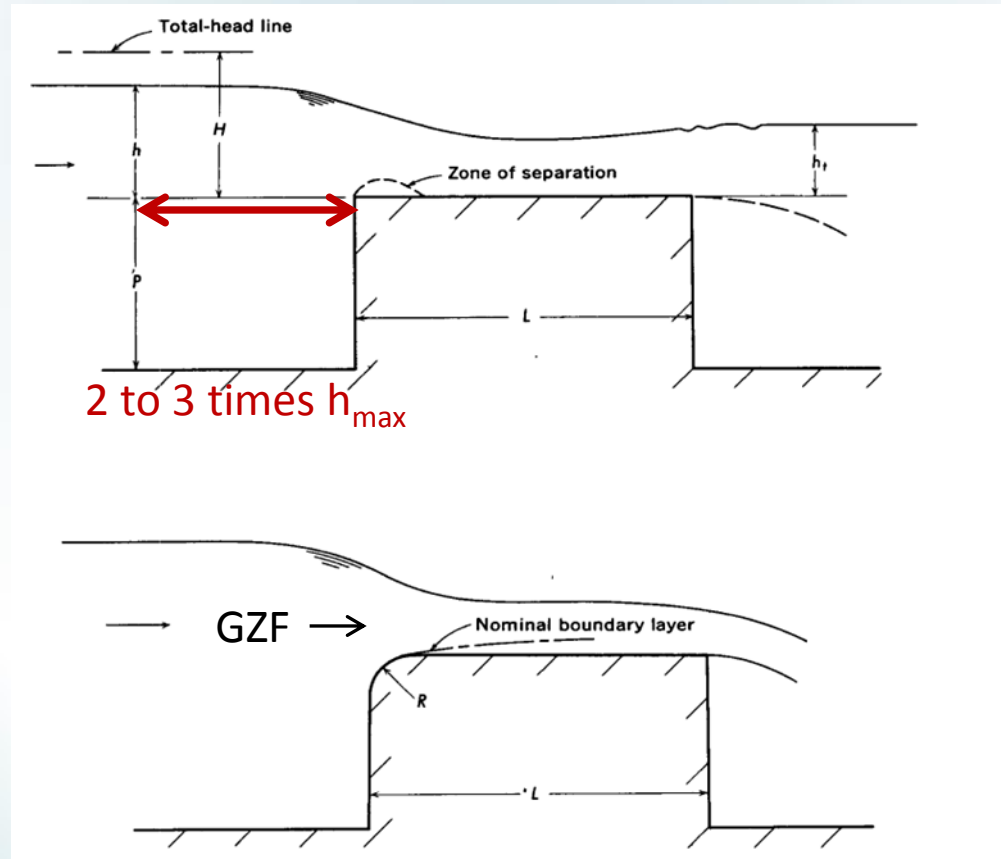
Stage Gages – installation location for sharp-crested weir



GZF = gage-height at zero flow

Measuring stage; non-recording reference gages

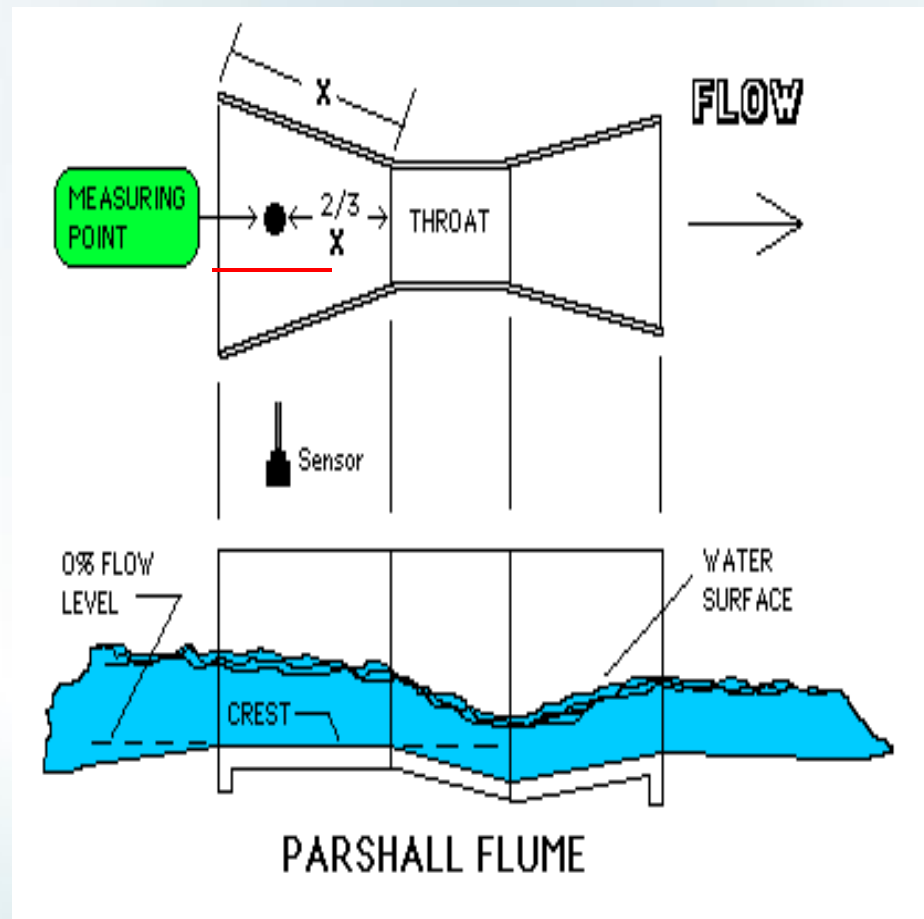
Stage Gages – installation location for broad-crested weir



GZF = gage-height at zero flow

Measuring stage; non-recording reference gages

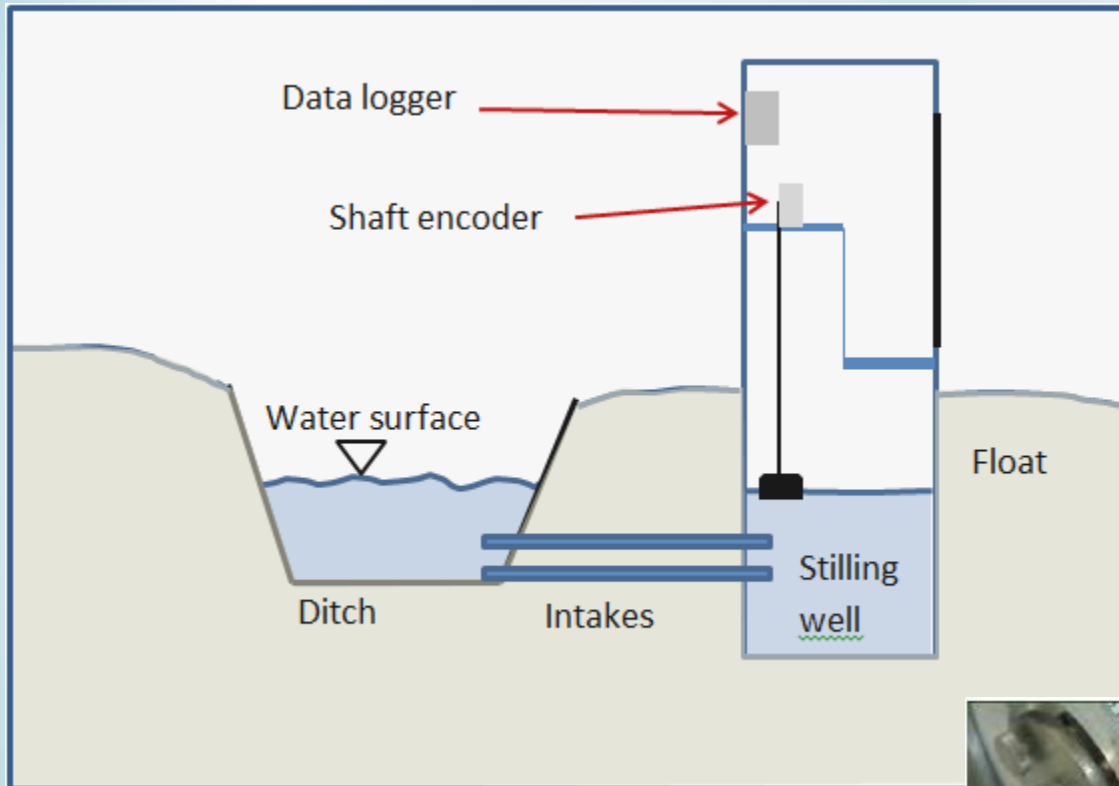
Stage Gages – installation location of Parshall flume



Water-Level Sensors for Continuous Monitoring

- Water-level sensors coupled with data loggers are used to automatically measure and record gage height.
- Gage-height data are downloaded and converted to discharge using a stage-discharge rating equation (discussed later).
- [Sauer and Turnipseed \(2010\)](#) provides an in-depth discussion of stage sensors, data loggers, and instrument shelters and discuss procedures for operation of a stage-measurement station.
- Non-recording reference gage is required to verify the water-level sensor is working correctly (sensors drift and deteriorate with age).
- [Rantz and others \(1982\)](#) explains the process for applying gage-height corrections to adjust sensor data to gage heights measured using a reference mark.

Water-Level Sensors – stilling well and float



Measuring stage

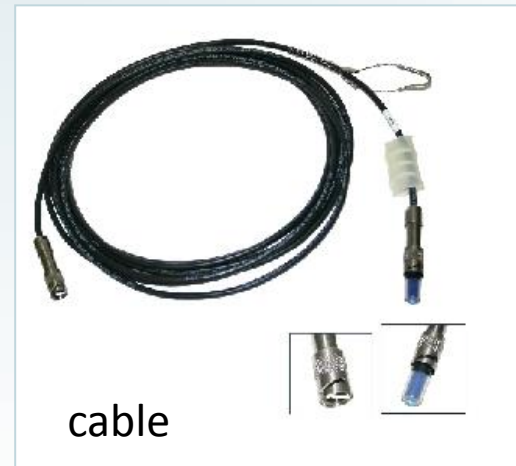
Water-Level Sensors – submersible pressure sensors



Non-vented sensor



sensor



cable

Vented sensor



desiccant pack

Measuring stage

Water-Level Sensors – non-submersible pressure sensors



Sutron Corp. Accububble
<http://www.sutron.com/>



Waterlog, Inc. H-3553 bubbler/pressure sensor
<http://www.waterlog.com/>

Measuring stage

Water-Level Sensors – non-contact (radar)

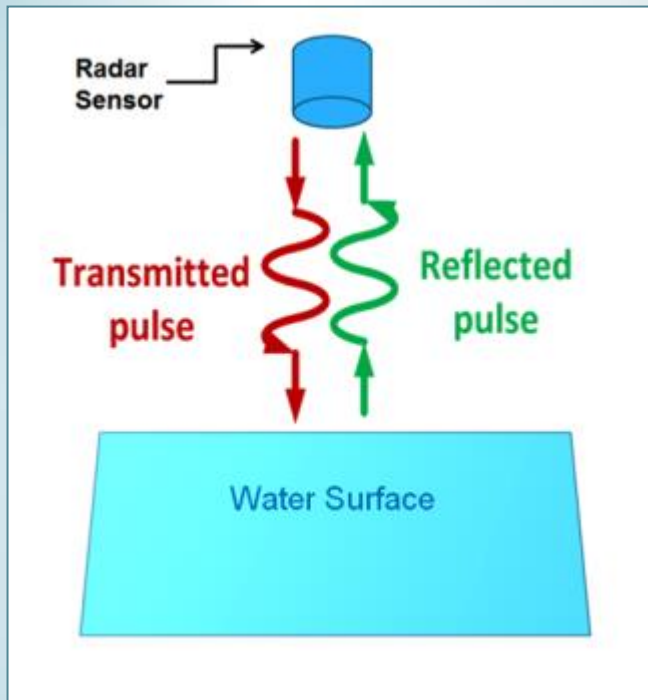


Diagram courtesy of Sutron Corp.

Waterlog, Inc.,
H-3611 radar water-level sensor
<http://www.waterlog.com/>



Sutron Corp. ,
RLR-003 radar level recorder
<http://www.sutron.com/>

Measuring stage

Water-Level Sensors – data loggers

- Many sensors require separate data loggers to record stage data
- Telemetry options available via satellite, phone modem, or fixed IP cell phone modem
- Many vendors sell complete packages of sensors and loggers and offer installation and setup



Measuring stage

Water-Level Sensors and Data Loggers – installation

Sensors

- Install near the non-recording reference gage. Installation should not interfere with ability to measure accurate gage-height from non-recording reference
- Must be mounted so they don't move around

Data loggers

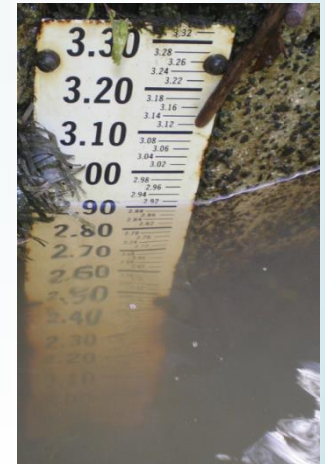
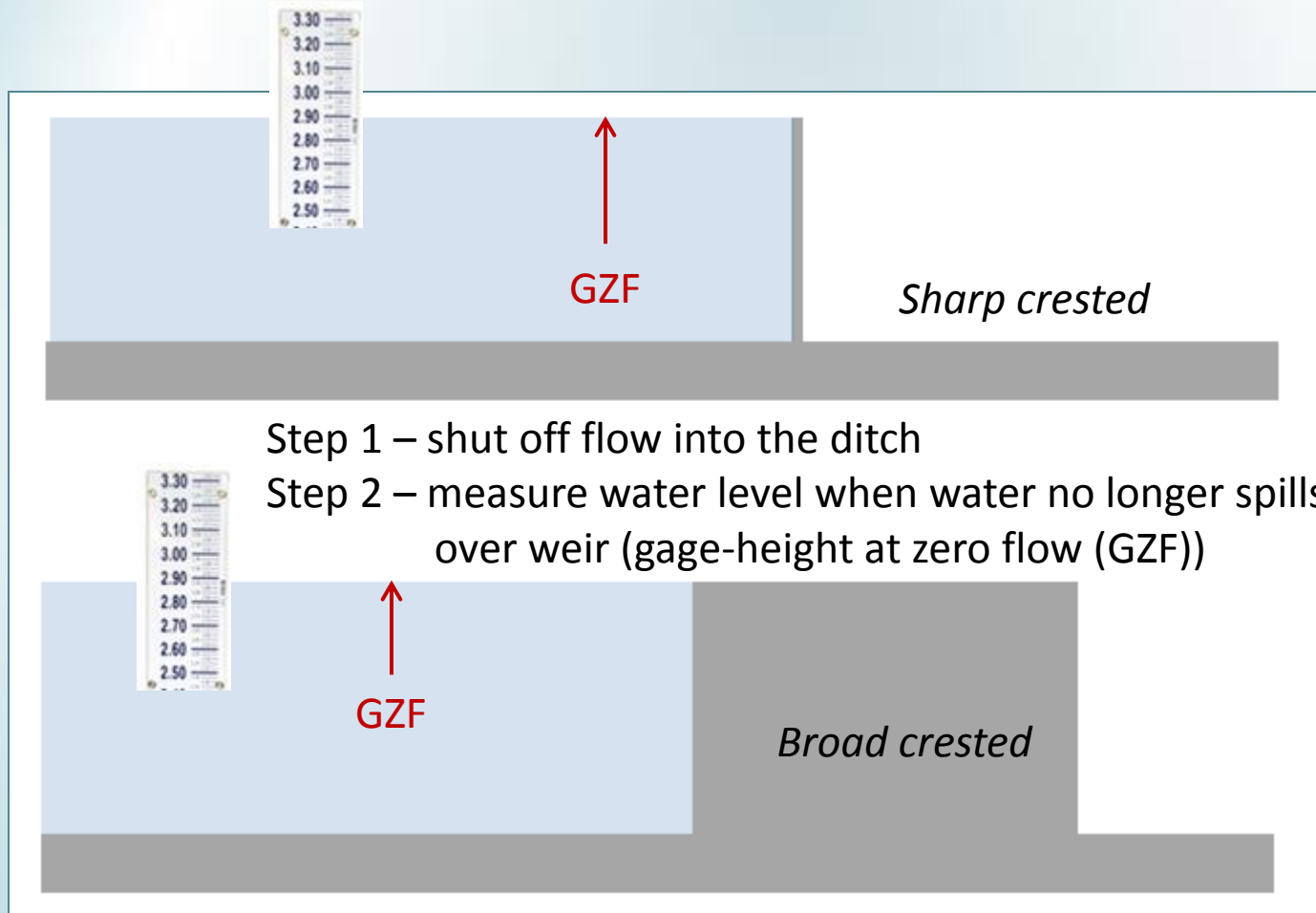
- Must have non-volatile memory
- Must use a vented instrument enclosure if using vented transducers when the vent line goes into the instrument shelter
- Recommend setting recording interval to 15-minutes. Interval should not exceed one hour.

Gage Datum

- Gage datum may be either a recognized datum such as Local Mean Sea Level or an arbitrary datum chosen out of convenience.
- Arbitrary datum recommended because we are measuring the change in gage height with discharge.
- Set the arbitrary datum to avoid negative values of gage height.
- Maintain a permanent gage datum for the life of the ditch-water measurements.

Measuring stage

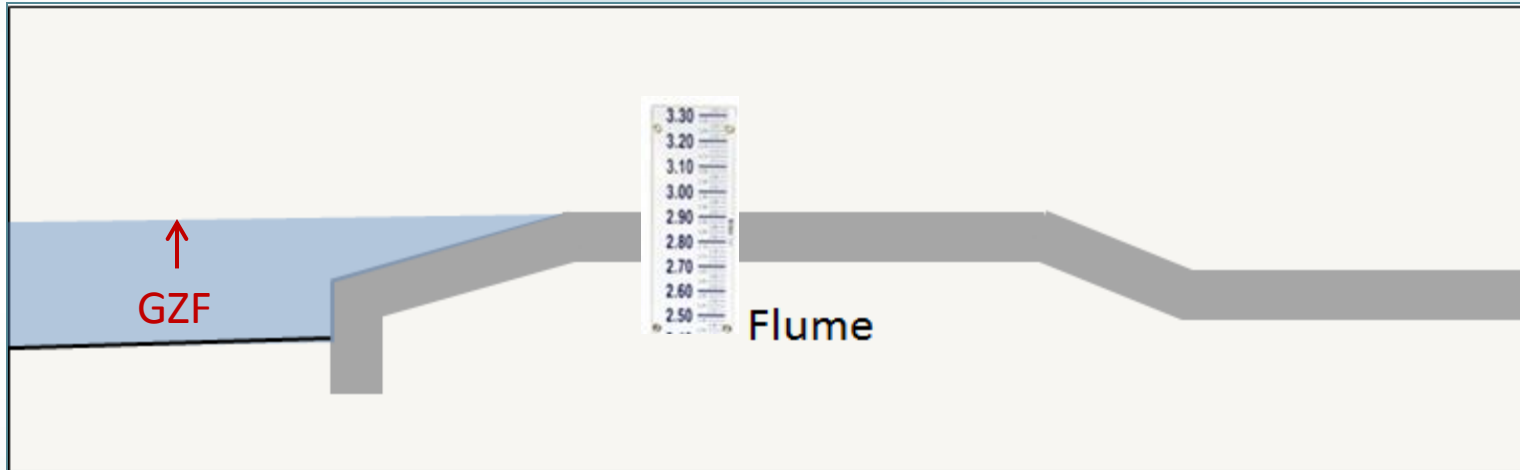
Setting Gage Datum – weirs



Weir equations use head which equals gage-height minus GZF

Measuring stage

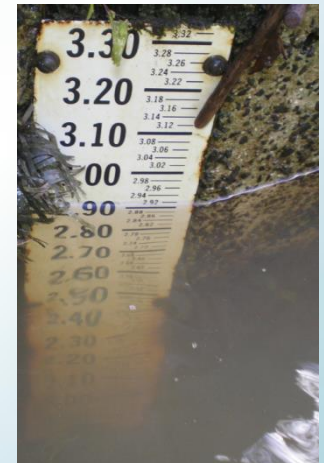
Setting Gage Datum – flumes



Step 1 – shut off flow into the ditch

Step 2 – measure water level when water no longer spills through flume throat

Flume equations use head which equals gage-height minus GZF



Measuring stage

Setting Gage Datum – open channels



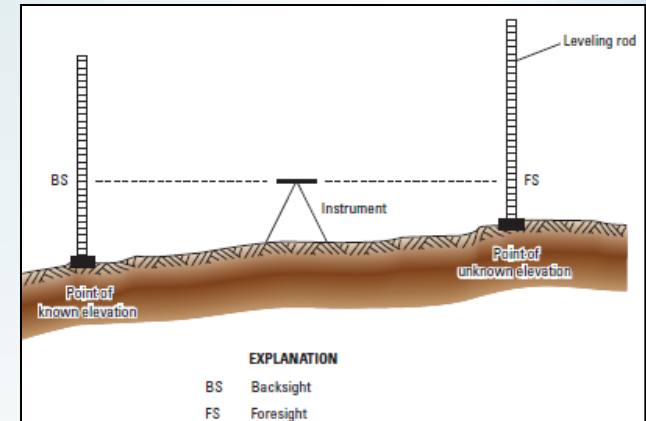
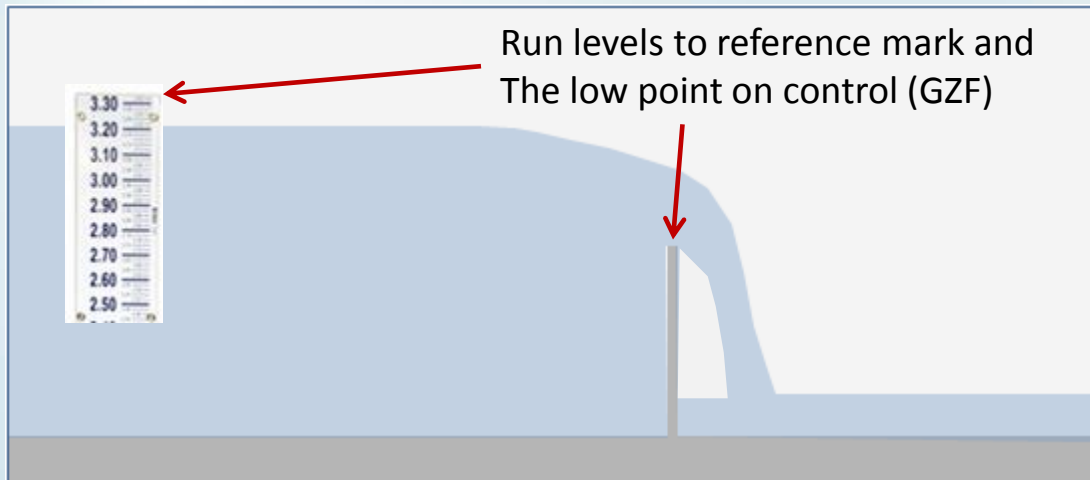
Step 1 – shut off flow into the ditch

Step 2 – measure water level when flow just stops

Stage-discharge equations use head which equals gage-height minus GZF

Measuring stage

Setting Gage Datum – what if I can't shut off the flow?



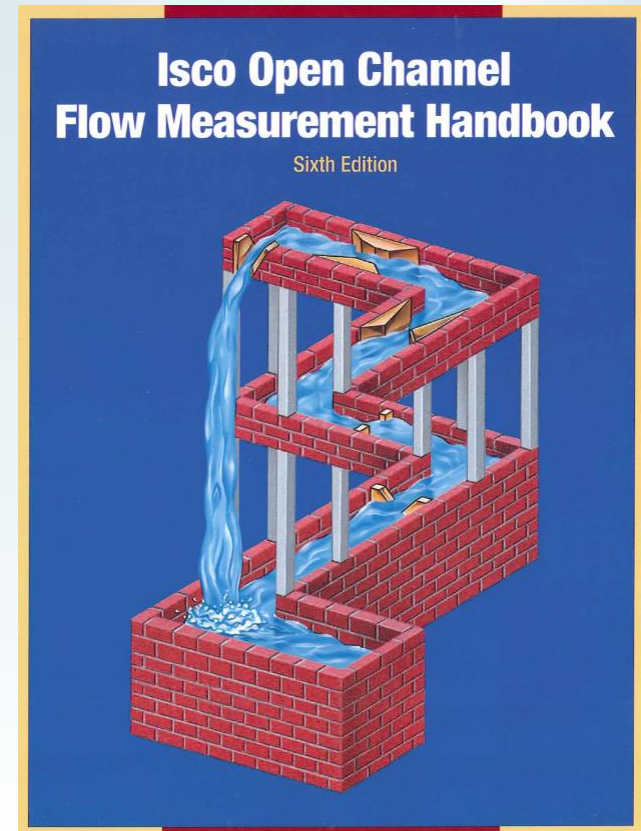
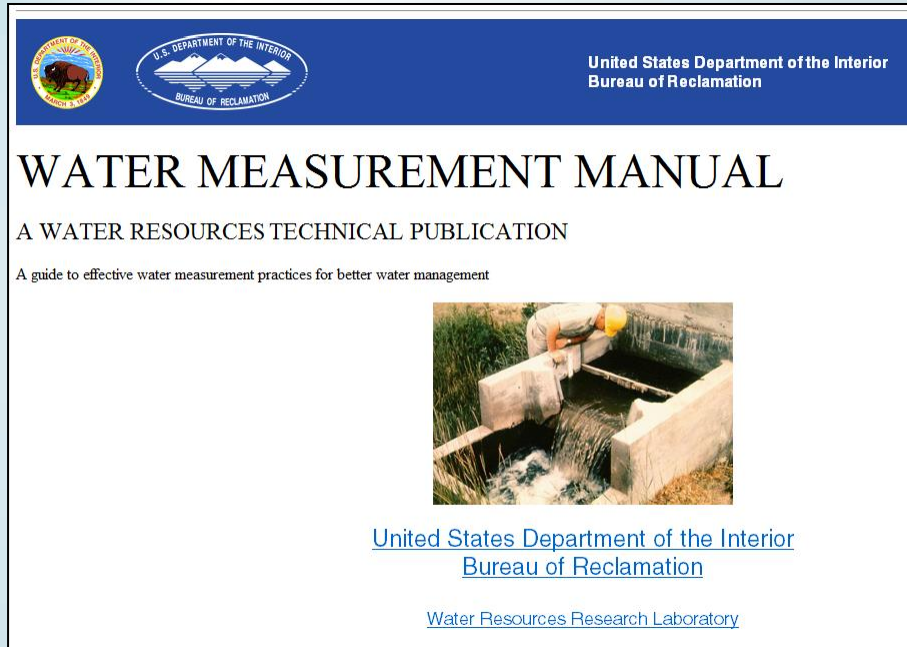
- Run a level survey to determine the elevation of the control and the non-recording reference mark (weir example shown here)
- For more information about leveling procedures, see [Kenny \(2010\)](#)

Measuring Discharge (ditch flow)

- The ditch operator needs to know the flow in the ditch (discharge) in order to compute water use
- Standard weirs and flume control features greatly simplify the measurement of discharge
- Other control types require additional effort and equipment to make direct measurements of discharge

Measuring discharge

Standard Weirs and Flumes



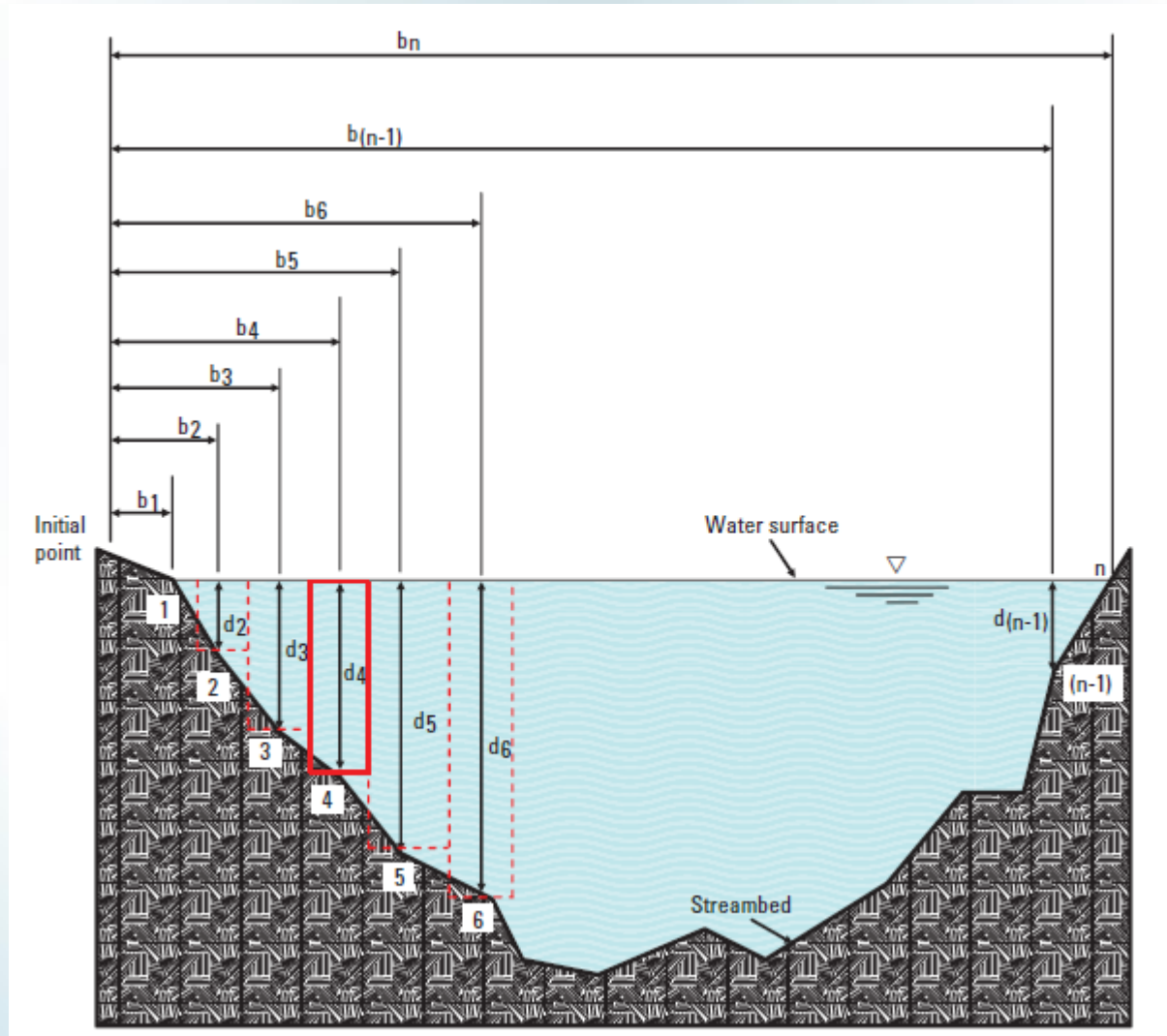
Remember -- equations and tables use head which equals gage-height minus GZF

Table and equations for many weir and flume designs are available from many sources.

Direct Discharge Measurements for Other Control Types

- Discharge is typically computed using the velocity-area method.
- Discharge is the product of the flow area (width x depth) and flow velocity.
- The ditch cross section is divided into several subsections.
- Mid-section method—USGS uses this method.
- The area of each subsection is determined by multiplying the subsection width by the depth.
- Average velocity is determined using a current meter to measure velocity at selected locations.
- The total ditch flow is the sum of the products of areas of the subsections of the ditch-flow cross section and their respective average velocities.
- See [Turnipseed and Sauer \(2010, p. 2\)](#) for more information.

Open Channel



Definition sketch of the current-meter mid-section method

Measuring discharge

What is a Good Section for Making a Discharge Measurement?

- Mid-section method involves selection of a good measuring section and proper current meter for the conditions encountered.
- The ditch measuring section must be close to the reference gage
- The measuring section should be in a straight portion of ditch with flow lines parallel to each other, free of large rocks or weeds, uniform bottom, even flow distribution across the cross section.
- Water velocity should be at least 0.2 ft/s and water depth greater than 0.3 ft to the extent possible.
- Measuring sections with slack-water and/or large rocks should be avoided.
- See [Turnipseed and Sauer \(2010, p. 8\)](#) for more information.

Measuring discharge

Area-Velocity Method to Compute Discharge

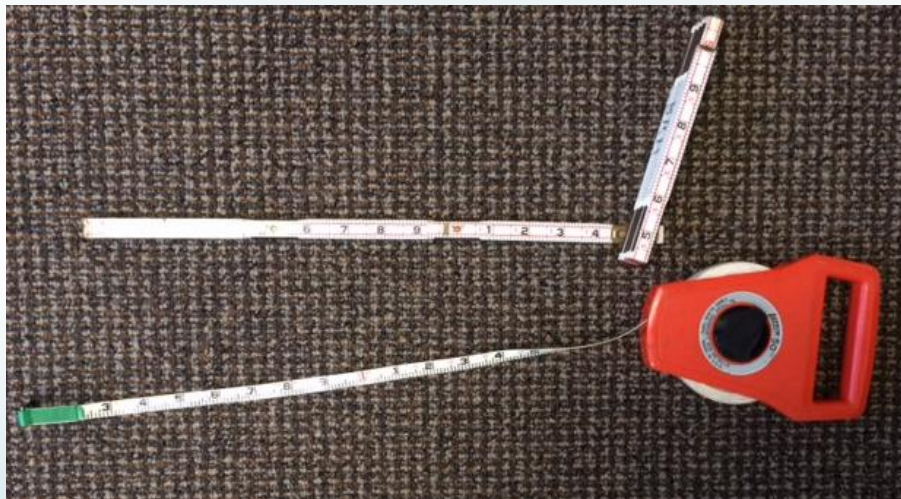
Components of the area-velocity method are width, depth, and velocity.

Computing discharge is easier if measurements are in decimal units of feet (not inches)

$$\begin{aligned}(\text{width} \times \text{depth}) &= \text{area} \\(\text{area} \times \text{velocity}) &= \text{discharge}\end{aligned}$$

Flow Width

- Measured by stringing a measuring tape perpendicular to the ditch flow lines at the measuring section.
- The most commonly used measuring tape for ditch measurements is a 25- or 50-ft survey tape marked in tenths of feet (rather than inches).
- A folding pocket ruler marked in tenths of feet can be used for ditches with a flow width less than 5 ft.



Flow Depth

- Measured using a wading rod.
- The wading rod is usually marked in tenths of feet and is designed for use with specific current meters.
- Some wading rods and current meters are built as a single unit and others are separate components.
- Wading rods are either fixed length (typically 4 ft) or telescopic, depending on the current meter used.
- If the measuring section is too deep or fast to safely wade, a bridge can be constructed across the ditch and a longer wading rod used.



Water Velocity

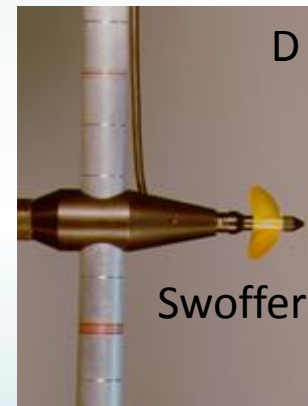
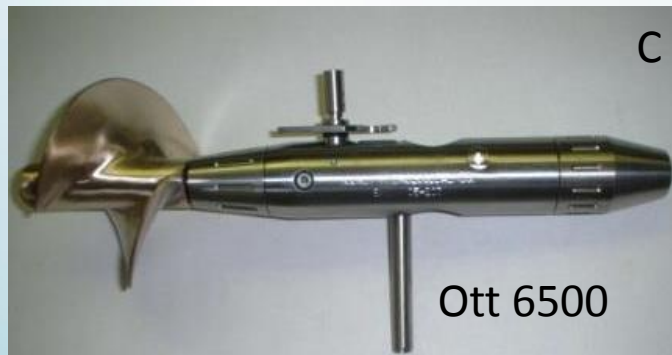
- Measured using a current meter.
- Always follow meter instructions for care, maintenance, and calibration check.
- Some current meters have integrated electronics to compute and display velocity.
- Some meters require separate purchase of stopwatch and headphones to count revolutions over a fixed time period, and a rating table to convert to the counts per time interval to velocity, or a measurement computer with built-in rating table.



Measurement of discharge (ditch flow) in open channels for non-standard controls

Mechanical Current Meters

- Mechanical meters measure point velocity.
- Designed with a rotor that spins in flowing water.
- The faster the water velocity, the faster the rotor spins.
- Two types of mechanical current
 - vertical axis (A and B)
 - horizontal axis (C and D)



Vertical-Axis Current Meters

- The Price AA and Price pygmy meters have been the work horse of the USGS for several decades.
- These meters are relatively inexpensive and can measure a wide range of velocity.
- Advantages of the vertical-axis current meter include the ability to accurately measure lower velocities than horizontal-axis current meters, the rotor is easily repairable/replaceable without affecting the velocity rating, bearing are protected from silt-laden water, and a single rotor serves for the entire range of velocities (Turnipseed and Sauer, 2010, p. 44).
- Vertical-axis current meters require regular cleaning and maintenance, and spin-test verification that they are working properly (Smoot and Novak, 1968).

Horizontal-Axis Current Meters

- Many models are designed with interchangeable propellers of different pitch to cover a wide range of velocities.
- They are slightly less likely to be entangled by debris relative to the vertical-axis meters.
- They are not as durable as vertical-axis meters and their bearings are more exposed to silt-laden water.
- They require regular cleaning and maintenance, and spin verification that they are working properly.
- Carefully follow the cleaning and testing instruction that come with the meter.
- More detailed information can be found in [Turnipseed and Sauer \(2010, p. 47\)](#).

Measurement of discharge (ditch flow) in open channels for non-standard controls

Non-Mechanical Current Meters

- These meters measure point velocities.
- They have no moving parts so require less maintenance than mechanical current meters.
- They require periodic diagnostic testing to ensure they are working properly.
- Follow manufacturer's testing instructions carefully.
- Non-mechanical current meters are more expensive than mechanical current meters.

Non-mechanical current meters

Electromagnetic current meter

- Measure water velocity by measuring the electric current produced when flowing water passes through a magnetic field.
- Advantages include no moving parts and direct readout of velocity.
- Not as accurate as the Price AA vertical-axis current meter in velocities less than 0.5 ft/s.
- More detailed information can be found in Turnipseed and Sauer (2010, p. 56).



Hach FH950

<http://www.hach.com/>

Non-mechanical current meters

Acoustic Doppler Velocimeter

- Measure water velocity indirectly using the Doppler principle.
- Actually measure the velocity of particles moving in the water.
- Advantages include no moving parts, direct readout of velocity, and the ability to sense lower velocities than mechanical current meters.
- Prone to measurement error in extremely clean (particle-free) water.
- Very sensitive to flow angle.
- More detailed information can be found in Turnipseed and Sauer (2010, p. 56).



SonTek FlowTracker
<http://www.sontek.com/>

Measurement of discharge (ditch flow) in open channels for non-standard controls

Meter Maintenance and Testing Log

- Regular maintenance and testing is essential to ensure any meter is functioning properly.
- Keep maintenance and testing log that lists cleaning and testing information by date.
- Record when parts have been replaced or other repairs have been made.

Measurement of discharge (ditch flow) in open channels for non-standard controls

Open-Channel Discharge Measurement – References

- More information on mid-section discharge measurements is USGS Water-Resources Investigations Report WRI-00-4036 ([Nolan and Shields, 2000](#)).
 - PowerPoint training used by the USGS to train hydrographers
 - Example used was a fairly wide stream but concepts of site selection and equipment apply to ditch measurements
 - Current meter used in the training example was a Price AA vertical-axis current meter
- Detailed instructions for making discharge measurements can also be found in [Turnipseed and Sauer \(2010\)](#).

Discharge and Site Inspection Notes for Open Channels

- [illegible]

60

Site Inspection Notes for Open Channels

Steps to help ensure a successful gage inspection:

1. Safety first -- upon arrival at the field site, look around for unsafe conditions.
2. Record ditch name, site location, date, and name of inspector(s) on a Discharge measurement and site inspection form.
3. Note and record the control type and control conditions. Control condition includes anything other than flow that affects the water level such as algae buildup, debris, leaks. If the control is clean and in good condition, write “clear.”
4. Record the time and gage height measured from the non-recording reference. If a reference point is used, be sure to write down the reference-point elevation, tape-up (or tape-down) and show the math used to obtain the gage height.

Site Inspection Notes for Open Channels – continued

5. Record the time and data logger water-level live reading.
6. Make a discharge measurement. Record meter type and serial number, measurement start and end times, and related quality assurance information. Compute measurement in the field .
7. Repeat steps 4 and 5.
8. Clean control and let water level stabilize.
9. Repeat steps 1 to 7 using a new Discharge measurement and site inspection form.
10. Download data from the data logger.

Converting Stage Data to Discharge (ditch flow)

- Standard weirs and flumes
 - use standard equations based on weir/flume size and type
 - Remember: Head (h) = gage-height – GZF
- Irregular weirs and other types of controls
 - Must make direct measurements of discharge for range of stages
- Stage-discharge equation takes the form of a power function
 - $Q = Ch^{2.5}$ for V-notch weir
 - $Q = Ch^{1.5}$ for rectangular weir
 - $Q = CbH^{1.5}$ for broad crested weir
 - $Q = Ch^{1.607}$ for Parshall flume
 - $Q = Ch^{x.xxx}$ for irregular control, break in slope control, and constriction control (exponent x.xxx needs to be determined)

[Q, discharge; C, constant; h, head; b, weir length; H, total energy head]

*An example at the end of this presentation shows how to set-up these equations using Excel.
Commercially available software for stage-discharge rating development is also available.*


Stage-Discharge Rating for Open-Channel Flow

- See [Rantz and others \(1982\)](#) for detailed information on rating development.
- Stage and discharge measurements covering the expected range of discharge are needed to properly define a rating.
- A good rule of thumb is to measure near each doubling of discharge over the expected range.
- The next few slides will walk through the process of developing a stage-discharge rating

Stage-discharge rating for open-channel flow

Stage-Discharge Rating Curve

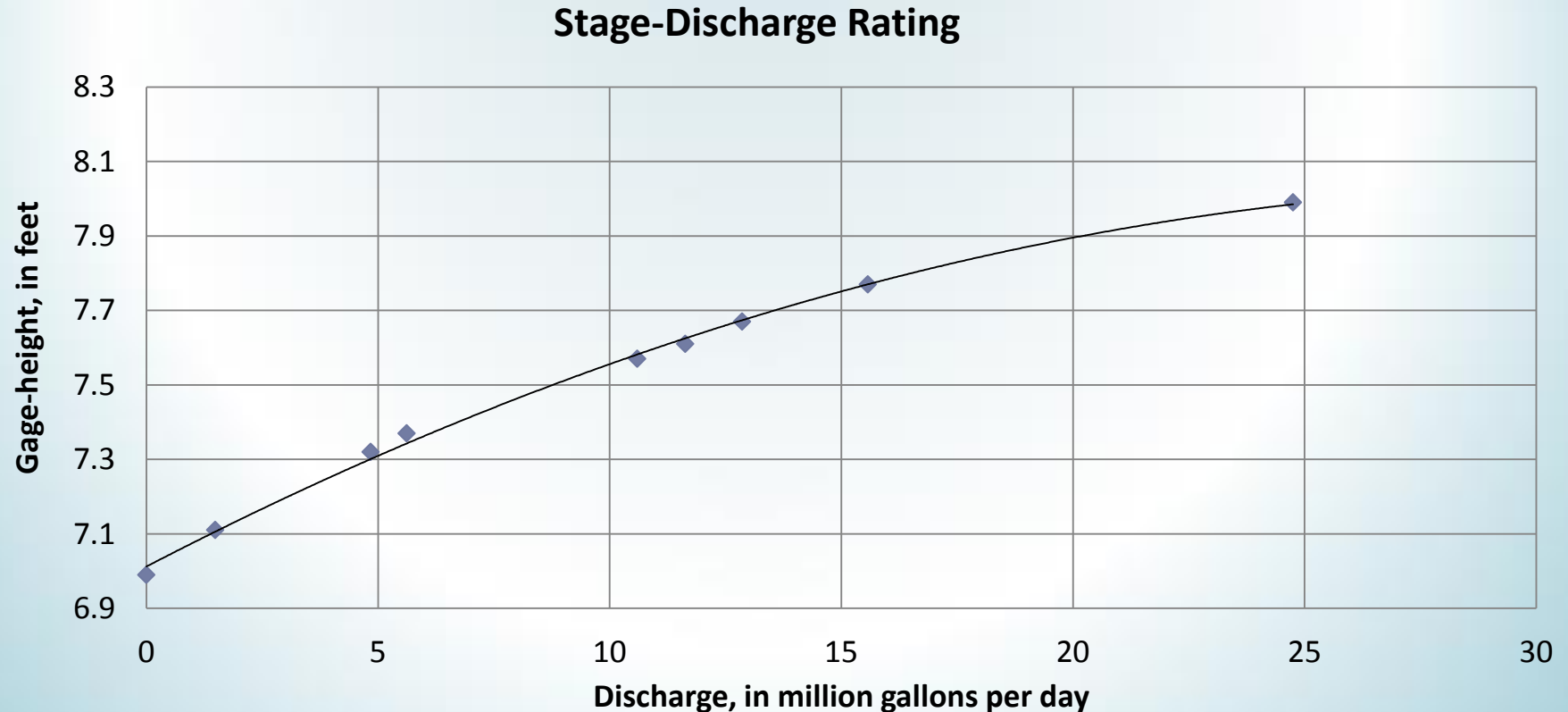
1. Subtract the gage-height at zero flow (GZF) from the measured gage heights associated with the discharge measurements.
2. Multiply discharge (ft^3/s) by 0.646317 to obtain discharge in million gallons per day (mgd)
3. Plot measurement gage height and discharge (mgd) pairs on log-log scale.

Gage-height (ft)	Gage height minus GZF (ft)	Discharge (ft^3/s)	Discharge (mgd)	Comments
6.99	not used	0.0	0.00	6.99 is gage-height at zero flow
7.00	0.01	0.1	0.06	estimated
7.11	0.12	2.3	1.5	Field measurements
7.32	0.33	7.5	4.8	
7.37	0.38	8.7	5.6	
7.57	0.58	16.4	10.6	
7.61	0.62	18.0	11.6	
7.67	0.68	19.9	12.9	
7.77	0.78	24.1	15.6	
7.99	1.00	38.3	24.8	

Stage-discharge rating for open-channel flow

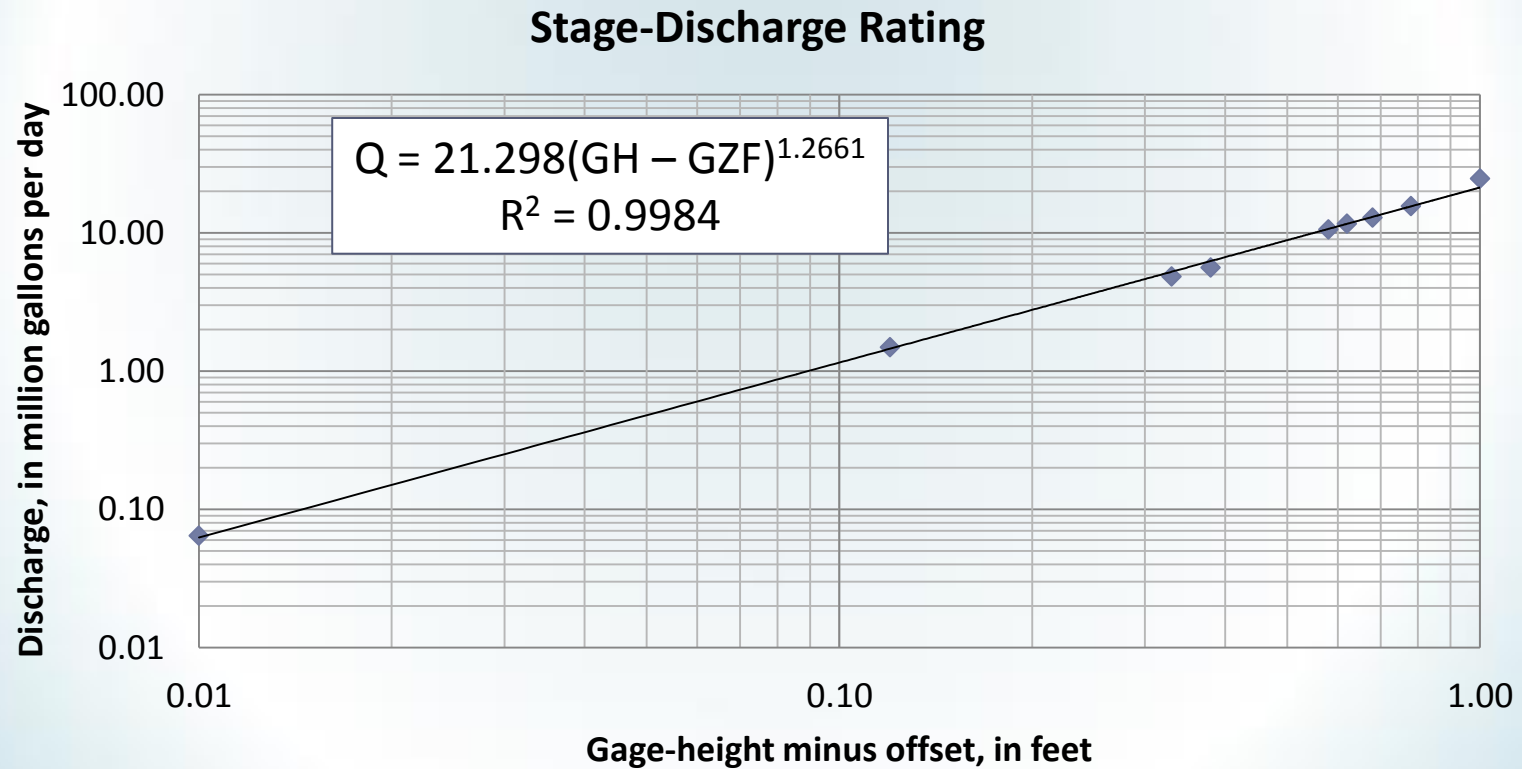
Stage-Discharge Rating Curve – linear plot

Using linear axis results in a curved line which is hard to work with when trying to convert values of gage-height to values of discharge.



Stage-discharge rating for open-channel flow

Stage-Discharge Rating Curve – log-log plot



See example of equation development at the end of this presentation.

Index-Velocity Method of Computing Discharge

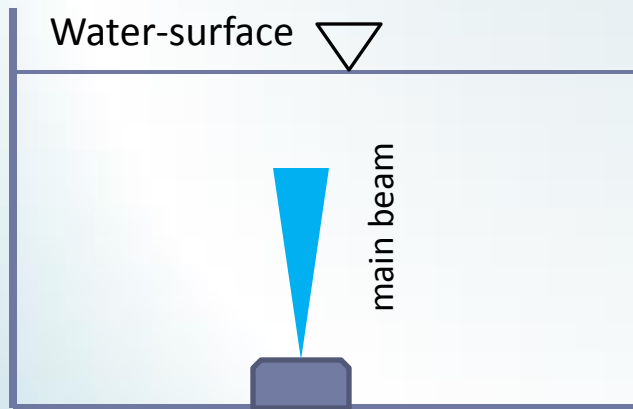
The index-velocity method utilizes instrumentation that measures gage height (previously covered) and velocity (acoustic doppler velocity meter - ADV) and is suitable for partially filled pipes and open-channel flow. Discharge is computed using the equation:

$$Q = VA \quad \text{where,}$$

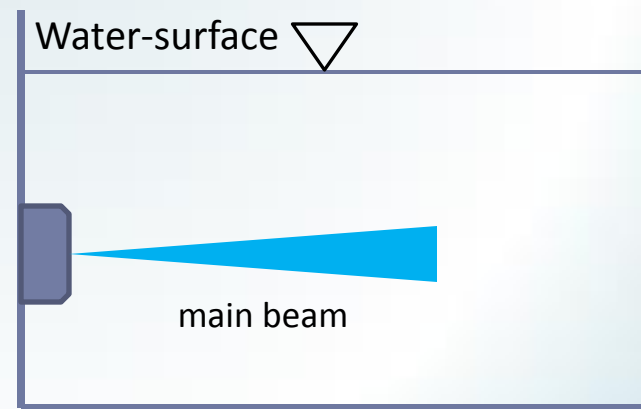
Q = discharge (ft^3/s)

V = average velocity for the cross section (ft/s)

A = cross section area across the ditch



Uplooker ADVM



Sidelooker ADVM

Index-Velocity Method of Computing Discharge

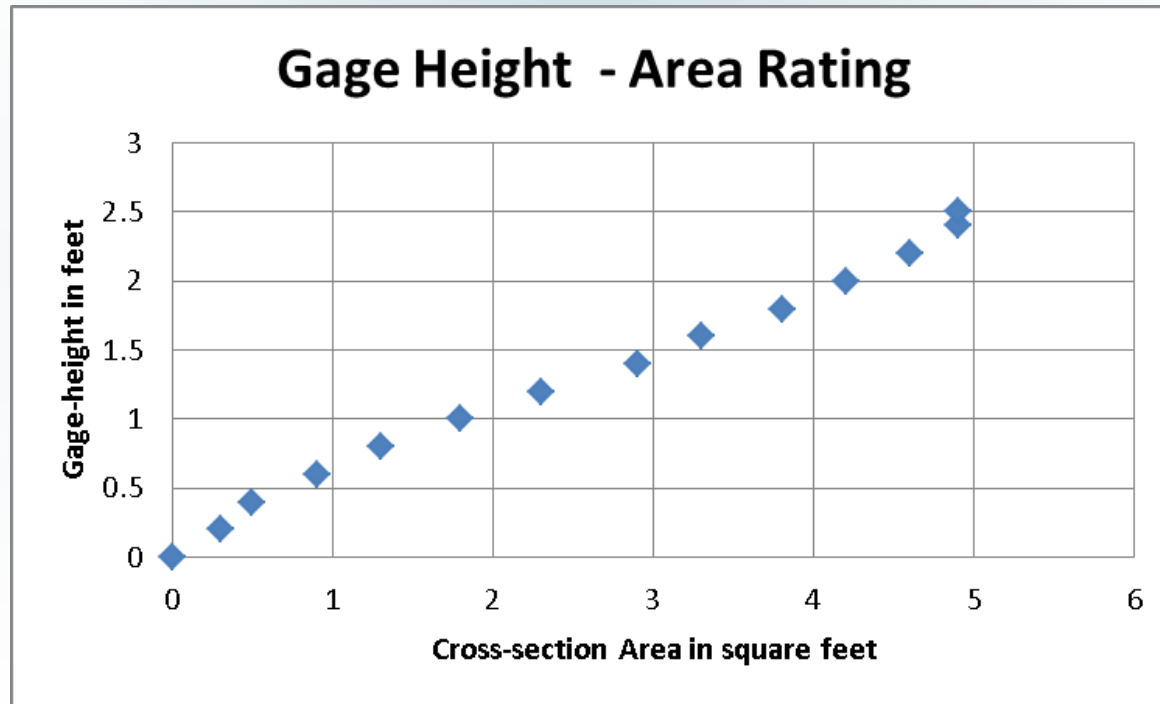
Velocity

- Measured using an acoustic doppler velocity meter (ADVM) connected to a data logger
- Uplooker ADVM may work for the relatively small and shallow Hawai'i ditches (minimum depth about 0.5 ft)
- Sidelooker ADVM requires about 5 ft minimum water depth
- ADVM measures velocity of a portion of the cross-section and must be adjusted to represent the mean velocity in the cross section
- Sidelookers can measure velocities up to 20 ft/s; uplookers, 16 ft/s

Area

- Measured as a function of gage height and channel width
- Gage-height is measured using instrumentation in earlier slide
- Requires detailed cross-section survey and a sensor to measure water level
- Up-looking ADVM measures both velocity and depth (gage height)

Index-Velocity Method of Computing Discharge



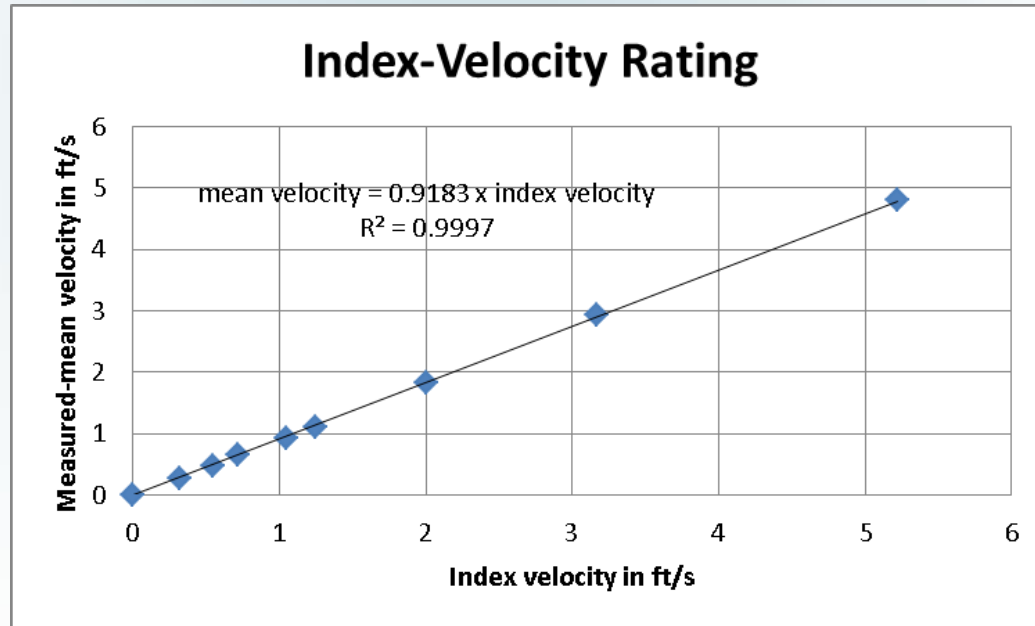
Example of an area rating for a 2.5-ft diameter circular pipe.

Two rating curves are developed:

The first is the gage height – area curve

The second rating curve required is the index-velocity curve that defines the relationship between the point velocity measured by the ADVN and the average velocity of the cross section that is obtained from direct discharge measurements (discussed earlier) at a range of gage-heights.

Example of an
index rating



The equipment is expensive and the method is complicated. It is best used for partial-filled pipes or concrete lined channels that by nature have a fixed gage height-area relation or open-channel ditches where variable backwater is a problem.

See [Levesque and Oberg \(2012\)](#) for more information.

Discharge Measurement in Pipes

Closed Channel – Full-Pipe (pressurized flow)

- Pressurized flow – no air space in pipe, completely full of water
- As with open-channels, discharge can be measured as a product of the cross-sectional area of the flow path times the mean velocity.
- Discharge measurement in a full pipe (pressurized flow) is easier than for an open channel because the cross section flow area is constant.
- The only variable of concern is the flow velocity inside the pipe.



Types of Meters that Measure Velocity in Closed (pressurized) Pipes

- Mechanical meter types include but are not limited to paddle wheel, turbine, and vane types.
- Non-contact meters include magnetic and acoustic types.
- Most have options for direct readout of discharge and many can be set-up to totalize flow.
- The disadvantage of full-pipe flow meters is there is no easy way to verify the accuracy of their readings.
- Manufacturers of these meters usually provide accuracy information for new meters but accuracy may decrease over time.
- Meter accuracy is also influenced by irregularities in the pipe such as bends in the pipe near the meter location.
- Meter installation instructions provide information on pipe section requirements.

Mechanical Meters for Closed (pressurized) Pipes



Photographs courtesy of Larry Schwankl,
University of California Cooperative
Extension



Acoustic and Electromagnetic Flow Meters for Closed (pressurized) Pipes



Acoustic

Photographs courtesy of Larry Schwankl,
University of California Cooperative
Extension

Electromagnetic



Discharge measurement in pipes

Partially-Full Pipe

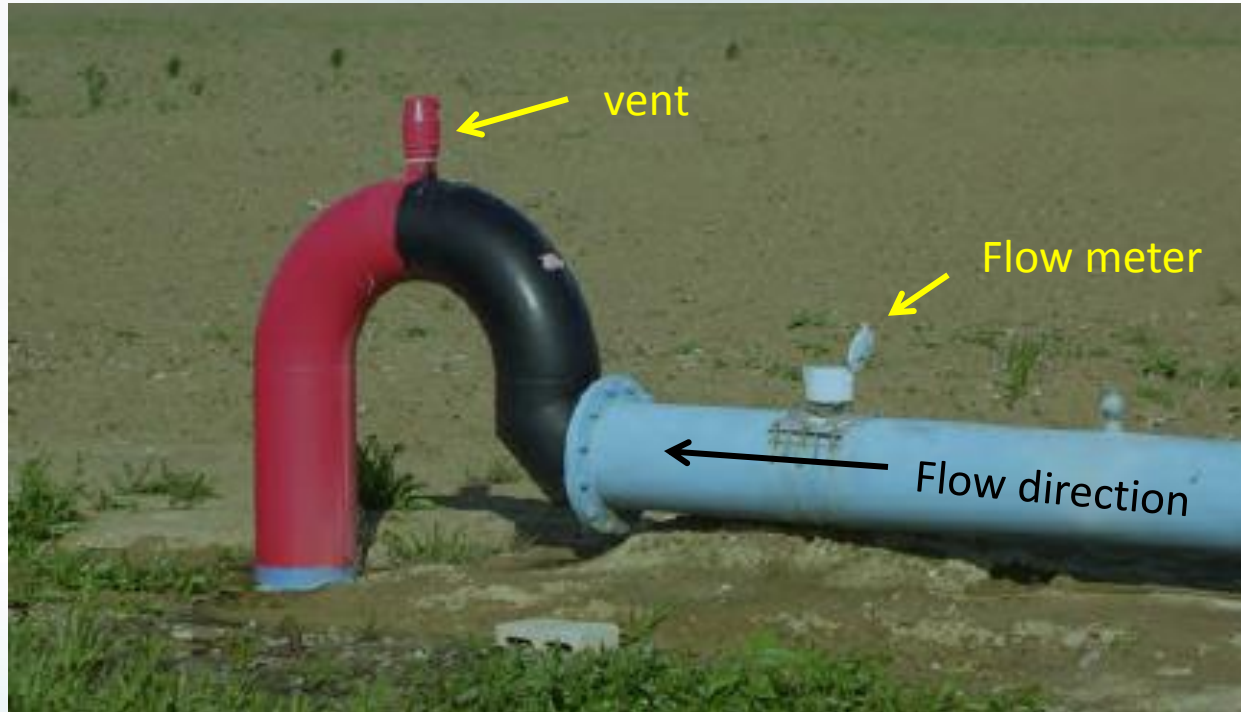
A partially-full pipe is an open channel and is measured using methods described for Open-channel flow.



Ditch operator should consider access issues if choosing to measure discharge in a partially-full pipe.

Discharge measurement in pipes

Partially-Full Pipe to Full Pipe Configuration



Site Inspection Notes

Steps to help ensure a successful gage inspection:

Full pipe

1. Safety first – upon arrival at the field site, look around for unsafe conditions.
2. Record ditch name, site location, data, and name of inspector(s).
3. Record time and flow-meter reading (totalizing flow meter).
4. Perform maintenance checks following instruction that came with the flow meter. Record results of this check on the field inspection form.

Partially-full pipe

1. Use same procedure for field notes as used for open-channel flow.

Computing Monthly Water Use

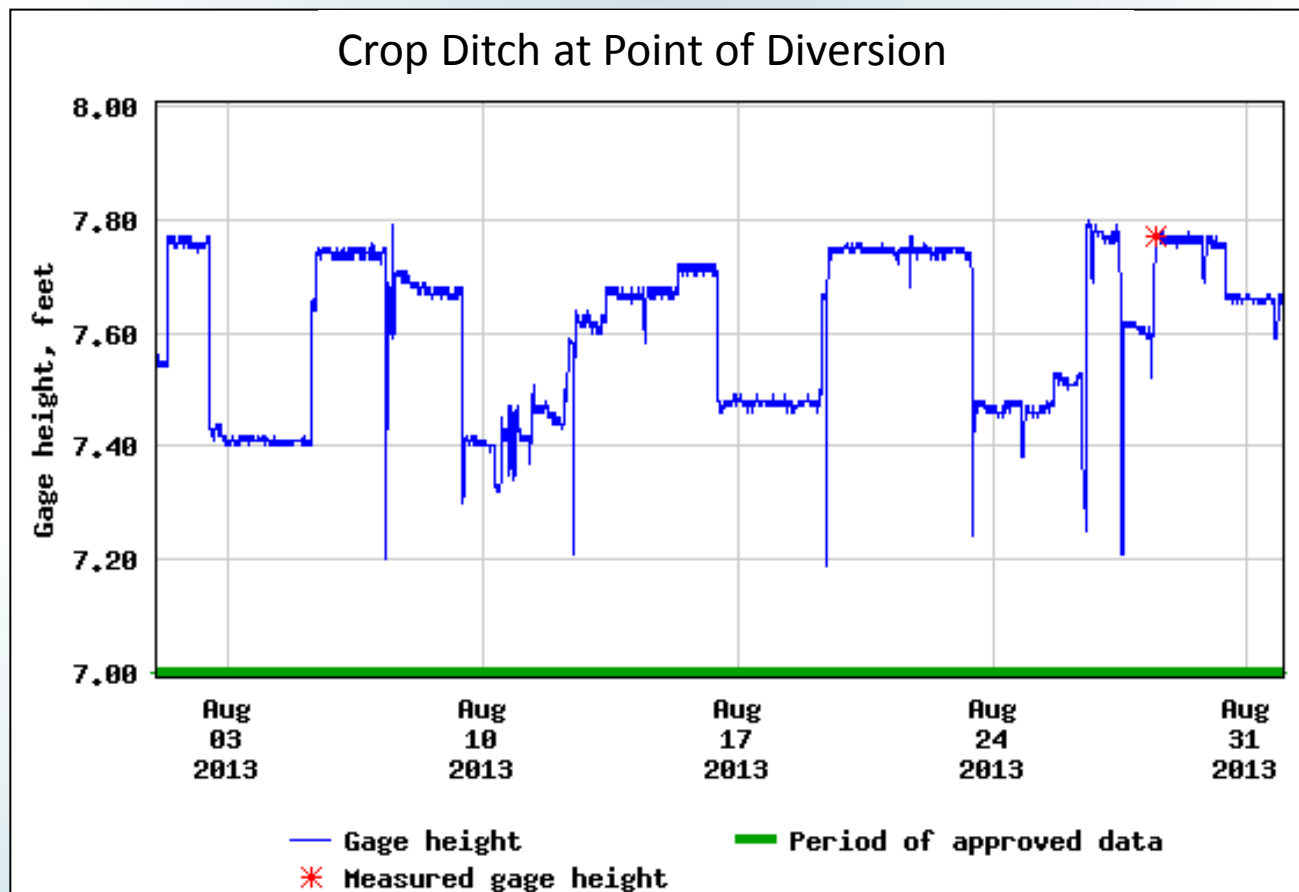
(reported in units of gallons)

1. Import data logger data into Microsoft Excel or spreadsheet of choice
 - a. Combine data sets as needed so there are data spanning the entire month
2. Compute discharge for each gage-height value using stage-discharge rating power equation
3. Compute the average of all of the discharge values using the AVERAGE function
4. Multiply the average discharge by the number of days in the month to get the total water use in gallons (or units of million gallons)

Accuracy using the average method is a function of the number and distribution of data values.

Computing monthly water use

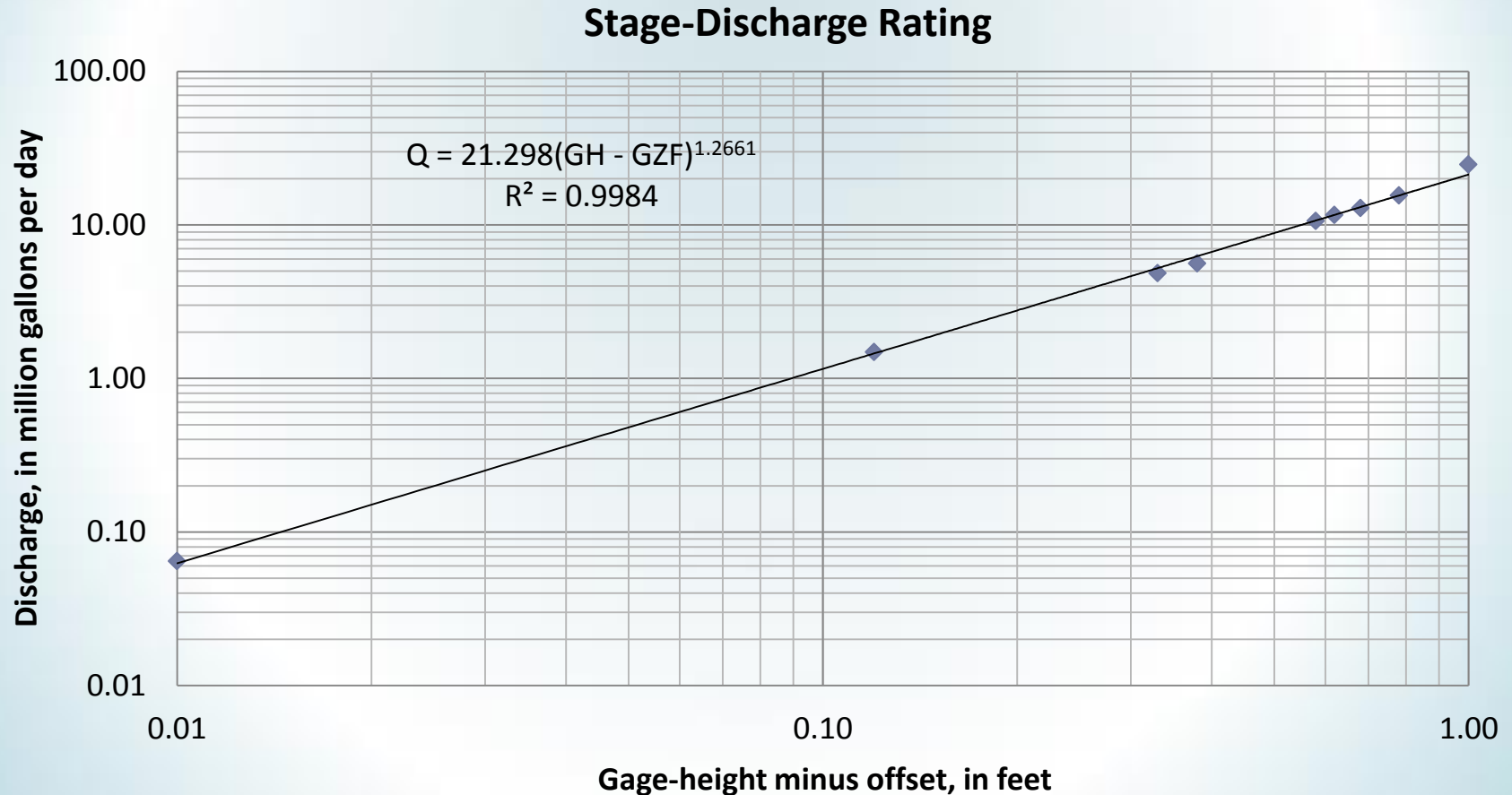
EXAMPLE – Crop Ditch, August 2013



Graph of Crop Ditch gage-height data collected every 15 minutes in August 2013.
(* denotes field-measured gage-height to verify gage was working correctly)

Computing monthly water use; EXAMPLE – Crop Ditch, August 2013

Given: Stage-Discharge Rating equation



See example of equation development at the end of this presentation

Computing monthly water use; EXAMPLE – Crop Ditch, August 2013

Step 1

Import data logger data for the month into Excel.

Rows 17 through 2974 were hidden to show row numbers for the entire month.

Excel Formula Bar: $= (21.298 * (\text{POWER}(B10 - 6.99, 1.2661)))$

Using power equation $Q(\text{mgd}) = 21.298(GH - 6.99)^{1.2661}$

	A	B	C	D	E	F	G	H	I
1									
2									
3									
4									
5									
6									
7									
8	date / time	GH, feet	Q(mgd)						
9									
10	8/1/2013 0:00	7.55	10.2						
11	8/1/2013 0:15	7.55	10.2						
12	8/1/2013 0:30	7.55	10.2						
13	8/1/2013 0:45	7.55	10.2						
14	8/1/2013 1:00	7.56	10.5						
15	8/1/2013 1:15	7.55	10.2						
16	8/1/2013 1:30	7.55	10.2						
2975	8/31/2013 22:00	7.65	12.6						
2976	8/31/2013 22:15	7.66	12.8						
2977	8/31/2013 22:30	7.67	13.1						
2978	8/31/2013 22:45	7.65	12.6						
2979	8/31/2013 23:00	7.66	12.8						
2980	8/31/2013 23:15	7.66	12.8						
2981	8/31/2013 23:30	7.66	12.8						
2982	8/31/2013 23:45	7.66	12.8						
2983									

Step 2

Compute Q(mgd) for each GH value using power equation derived from graph.

Computing monthly water use; EXAMPLE – Crop Ditch, August 2013

The screenshot shows an Excel spreadsheet with the following data:

	A	B	C	D	E	F	G	H	I
1									
2	Design Analysis								
3	Waterlog -- H-522Plus DATAFILE								
4	Sensor Serial # = S#001774 V4.41								
5	Filename = 16210100.022								
6									
7	Average unit discharge, mgd 11.6								
8	date / time	GH, feet	Q(mgd)	Total (average mgd x 31 days) 359.8					
9									
10	8/1/2013 0:00	7.55	10.2						
11	8/1/2013 0:15	7.55	10.2						
12	8/1/2013 0:30	7.55	10.2						
13	8/1/2013 0:45	7.55	10.2						
14	8/1/2013 1:00	7.56	10.5						
15	8/1/2013 1:15	7.55	10.2						
16	8/1/2013 1:30	7.55	10.2						
2975	8/31/2013 22:00	7.65	12.6						
2976	8/31/2013 22:15	7.66	12.8						
2977	8/31/2013 22:30	7.67	13.1						
2978	8/31/2013 22:45	7.65	12.6						
2979	8/31/2013 23:00	7.66	12.8						
2980	8/31/2013 23:15	7.66	12.8						
2981	8/31/2013 23:30	7.66	12.8						
2982	8/31/2013 23:45	7.66	12.8						
2983									

The formula bar shows the formula: $\text{=AVERAGE(C10:C2982)}$

The result of the formula is 11.6, which is highlighted in a red box. A red arrow points from the formula bar to the result cell.

Step 3
Compute average Q(mgd) using the Excel AVERAGE formula.

Final step
Multiply the average times number of days in the month to obtain monthly water use.

Step 3

Compute average Q(mgd) using the Excel AVERAGE formula.

Final step

Multiply the average times
number of days in the
month to obtain monthly
water use.

Rows 17 through 2974
were hidden to
show row numbers
for the entire month.

Reporting Water Use to the Commission on Water Resource Management

The following information are provided on a monthly basis:

- Gage ID and name
- Reporting period
- Monthly water use (gallons)
- Method of measurement

Contact CWRM for information and instructions on reporting forms and online reporting.

Commission on Water Resource Management

P.O. Box 621

Honolulu, HI 96809

(808) 587-0214

<http://dlnr.hawaii.gov/cwrn/info/waterusereport/>

Reporting water use to CWRM



State of Hawaii
COMMISSION ON WATER RESOURCE MANAGEMENT
Department of Land and Natural Resources
MONTHLY SURFACE WATER USE REPORT

For Official Use Only:

Name: _____

Company: _____

Address: _____

Telephone No.: _____ **Fax No.:** _____

Report Month: _____ **Year:** _____

Report PID: _____

SWUR ID: _____

INSTRUCTIONS: Please TYPE or PRINT CLEARLY. Complete this form to report total monthly surface water use from each of your sources and/or gaging stations. For assistance, contact the Stream Protection and Management Branch at (808) 587-0234.
Electronic submissions: Complete and digitally sign (*checkbox*) this form, then send file via e-mail to: dlmr.cwrmm@hawaii.gov
Hardcopy submissions: Complete, print and sign this form, then send printed report via mail to: Commission on Water Resource Management, P.O. Box 621, Honolulu, HI 96809. To submit report via facsimile, send to (808) 587-0219.

Gage ID*	Gage Name	Period Begin Date (mm/dd/yy)	Period End Date (mm/dd/yy)	Quantity Measured (gallons)	Method of Measurement**

* The Gage ID should be obtained from the Commission on Water Resource Management.

** Flow meter, electrical consumption, weir or flume, not metered (estimated).

Other comments or additional information (e.g., date and method of chloride measurement, how pumpage amounts are estimated, etc.):

Submitted by (print name): _____ **Title:** _____

For electronic submissions:

☐ By checking this box, I understand and affirm that the information provided herein is accurate and true to the best of my knowledge.

Date: _____

For hardcopy submissions:

Signature: _____ **Date:** _____

By signing here, I understand and affirm that the information provided herein is accurate and true to the best of my knowledge.

SWUR-MON FORM (08/06/2010)


Reporting water use to CWRM

File Edit View History Bookmarks Tools Help

Surface Water Use Report

cwrn.dlnr.hawaii.gov/cwrmpublic/EnterDataSurface.aspx

Most Visited NPR : National Public ... Yahoo! Hawaii Drought Monitor Rainfall Atlas of Hawa... Map of Drought Impa... State of Hawaii eProc... Home - Hawaii State ... National Weather Ser...

 **Hawaii State Water Use Reporting**
Commission on Water Resource Management (CWRM)
Department of Land and Natural Resources, State of Hawaii

Logged in as: 013215 John Doe (Doe Farms) [Logout](#)

Water Use Report (Surface)

General Information

WUR ID
[Auto Number]

Reporter

Reporter
John Doe (Doe Farms)

Dates

Begin Date: 03/01/2014 End Date: 03/31/2014 Days Count: 31 [Auto Fill Dates](#)

Memo

Gage Data

Gage ID	Gage Name	Period Begin Date (mm/dd/yyyy)	Period End Date (mm/dd/yyyy)	MG	Gallons	MGD	CFS	Gage Method
80	Kahe Stream Diversion	03/01/2014	03/31/2014	1.000	1000000	0.032	0.050	Continuous

<http://dlnr.hawaii.gov/cwrn/info/waterusereport/>

Questions ?

Suggested References

Hulsing, Harry, 1967, Measurement of peak discharge at dams by indirect methods: U.S. Geological Survey Techniques and Methods, book 3, chap. A5, 29 p.

International Organization for Standardization, 1997, Measurement of liquid flow in open channels – Velocity-area methods, ISO 748:1997E, 41 p.

Kilpatrick, F.A, and Schneider, V.R., 1983, Use of flumes in measuring discharge: U.S. Geological Survey Techniques and Methods, book 3, chap. A14, 46 p.

Levesque, V.A., and Oberg, K.A., 2012, Computing discharge using the index velocity method: U.S. Geological Survey Techniques and Methods, book 3, chap. A23, 148 p.

Nolan, K.M., and Shields, R.R., 2000, Measurement of stream discharge by wading: U.S. Geological Survey Water-Resources Investigations Report 00-4036, version 1.1 (Microsoft Powerpoint on CD-ROM).

Rantz, S.E., and others, 1982, Measurements and computation of streamflow, volumes 1 and 2: U.S. Geological Survey Water-Supply Paper 2175, 631 p.

Suggested References – continued

Sauer, V.B., and Turnipseed, D.P., 2010, Stage measurement at gaging stations: U.S. Geological Survey Techniques and Methods, book 3, chap. A7, 45 p. (Also available at <http://pubs.usgs.gov/tm/tm3-a7/>.)

Smoot, G.F. and Novak, C.E., 1968, Calibration and maintenance of vertical-axis type current meters: U.S. Geological Survey Techniques of Water-Resource Investigation, book 8, chap. B2, 15 p.

Turnipseed, D.P., and Sauer, V.B., 2010, Discharge measurements at gaging stations: U.S. Geological Survey Techniques and Methods, book 3, chap. A8, 87 p. (Also available at <http://pubs.usgs.gov/tm/tm3-a8/>.)

Walkowiak, D.K., 2013, ISCO open channel flow measurement handbook (6th ed.): Teledyne Technologies Incorporated, 520 p.

Weirs and flumes

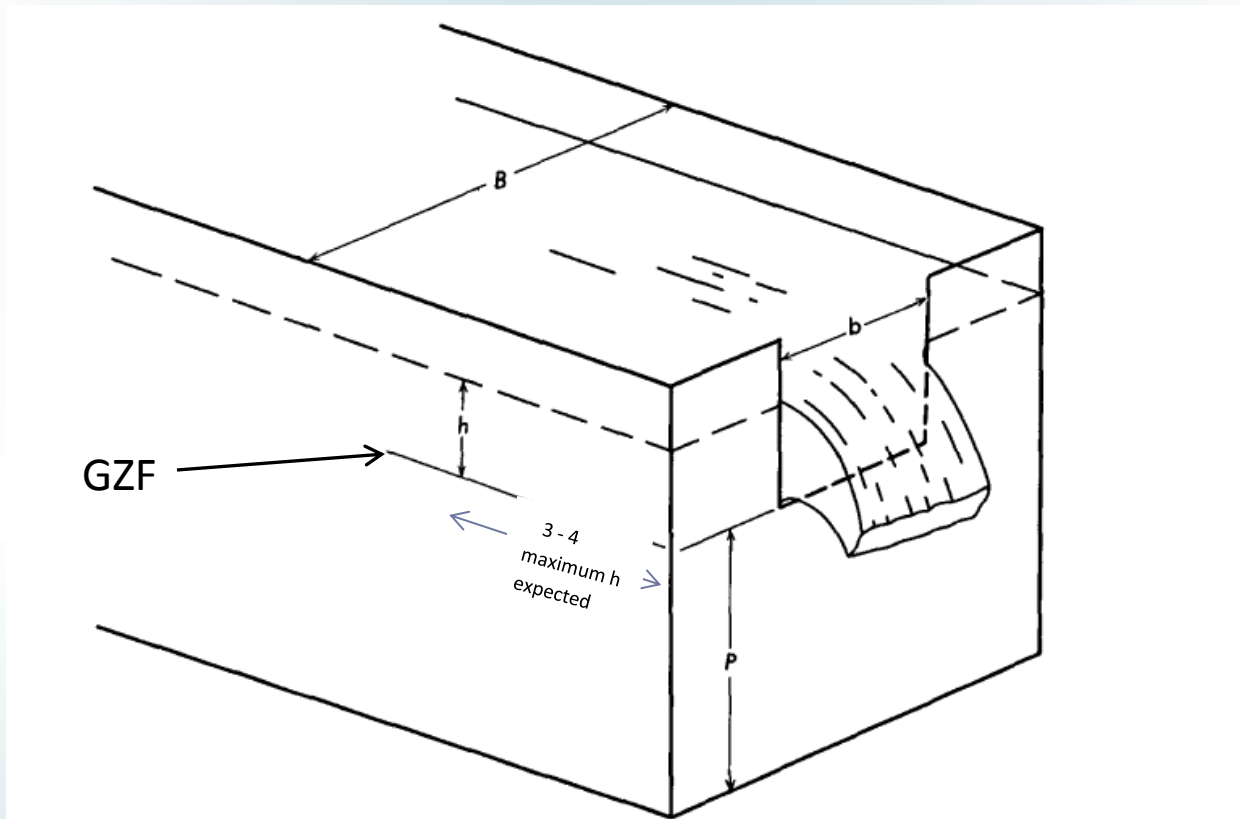
Stage-discharge rating for open-channel flow

Considerations for Weirs and Flumes

- Use of theoretical equations for weirs and flumes was previously mentioned when controls were discussed.
- Equations are useful but may or may not be accurate depending on the condition of the structure.
- USGS protocol requires stage-discharge ratings developed from direct measurement of discharge.
- Use of theoretical weir and flume equations is accepted by the State of Hawai'i Commission on Water Resource Management

Measuring flow in a weir

Flow Over a Rectangular Sharp-Crested Weir



GZF = gage-height at zero flow

Schematic from [Hulsing \(1967\)](#), p. 5.

Measuring flow in a weir

Flow Over a Rectangular Sharp-Crested Weir – continued

The basic equation for a sharp-crested weir provides an approximation of discharge:

$$Q = Cbh^{1.5}$$

Where

Q = discharge (ditch flow)

C = discharge coefficient

b = width of the weir crest

h = head on the weir

Measuring flow in a weir

Flow Over a Rectangular Sharp-Crested Weir – continued

Discharge coefficient, C

- Function of the relation between head and pool depth
- Function of the ratio of weir crest to pool width
- Can be estimated using the procedures in [Hulsing \(1967\)](#)

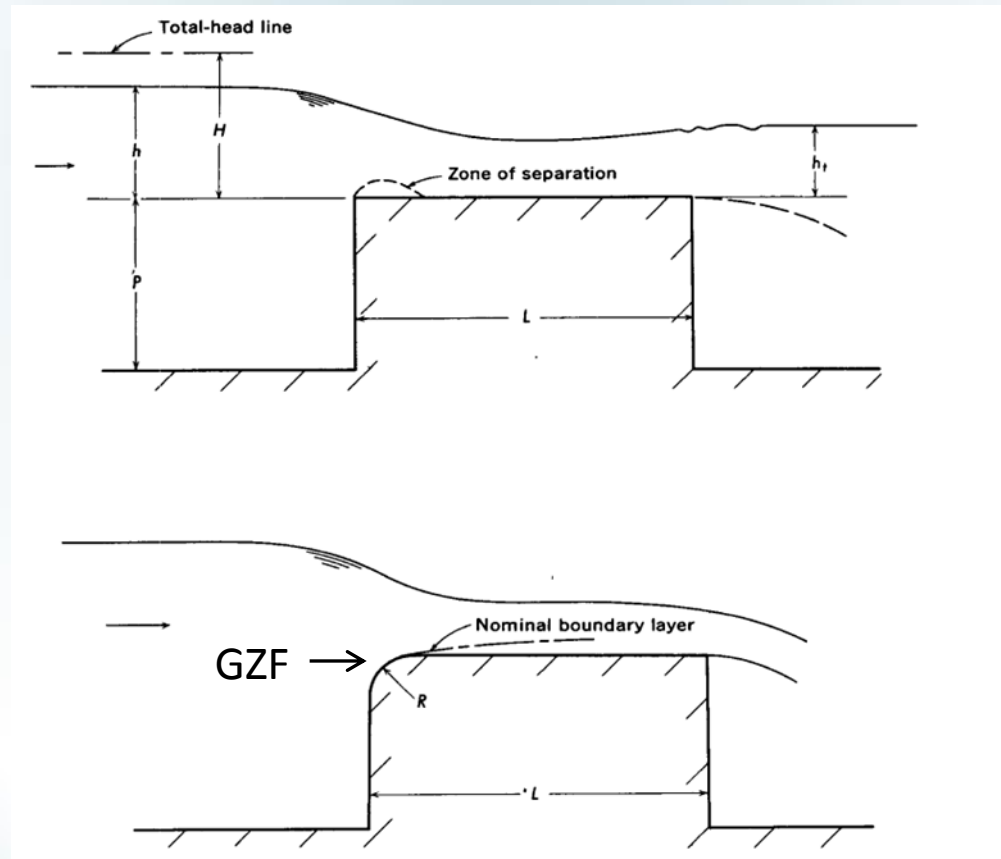
Standard equations assume a value of C which may or may not be accurate for a particular weir.

The USGS measures discharge directly in lieu of the equation

- If a ditch operator chooses to use the equation, periodic direct discharge measurements should be made to verify that the equation is still applicable.

Measuring flow in a weir

Flow Over a Broad-Crested Weir



GZF = gage-height at zero flow

Schematic from [Hulsing \(1967\)](#), p. 8.

Measuring flow in a weir

Flow Over a Broad-Crested Weir – continued

The basic equation for a broad-crested weir provides an approximation of discharge:

$$Q = CbH^{1.5}$$

Where

Q = discharge (ditch flow)

C = discharge coefficient

b = width of the weir crest

H = total energy head ($h + V_1^2/2g$)

Where

h = head on the weir

g = gravitational constant, 32 ft/sec²

V = mean velocity of flow in the section, ft/sec

Flow Over a Broad-Crested Weir – continued

The discharge coefficient, C

- Function of the relation between head and weir length
- Function of degree of rounding, R , on the upstream edge of weir
- Function of the slope upstream and downstream of the weir face
- Can be estimated using the procedures in [Hulsing \(1967\)](#)

Transition from broad-crested to sharp-crested weir

- A concrete rectangular weir that is one half foot thick will react as a broad-crested weir up to a depth of about 0.6 ft and as a sharp-crested weir at higher heads.

Standard equations assume a value of C which may or may not be accurate for a particular weir.

The USGS measures discharge directly in lieu of the equation

- If a ditch operator chooses to use the equation, periodic direct discharge measurements should be made to verify that the equation is still applicable.

Measuring flow in a weir

Concrete Rectangular Weirs in Hawai'i

- Found on many ditches
- Have various thicknesses
- Act as sharp crested weir at medium and higher heads
- Act as broad-crested weir at low heads
- See [Hulsing \(1967\)](#) for more information on other types of weirs

Considerations for Discharge Computation Using Weirs

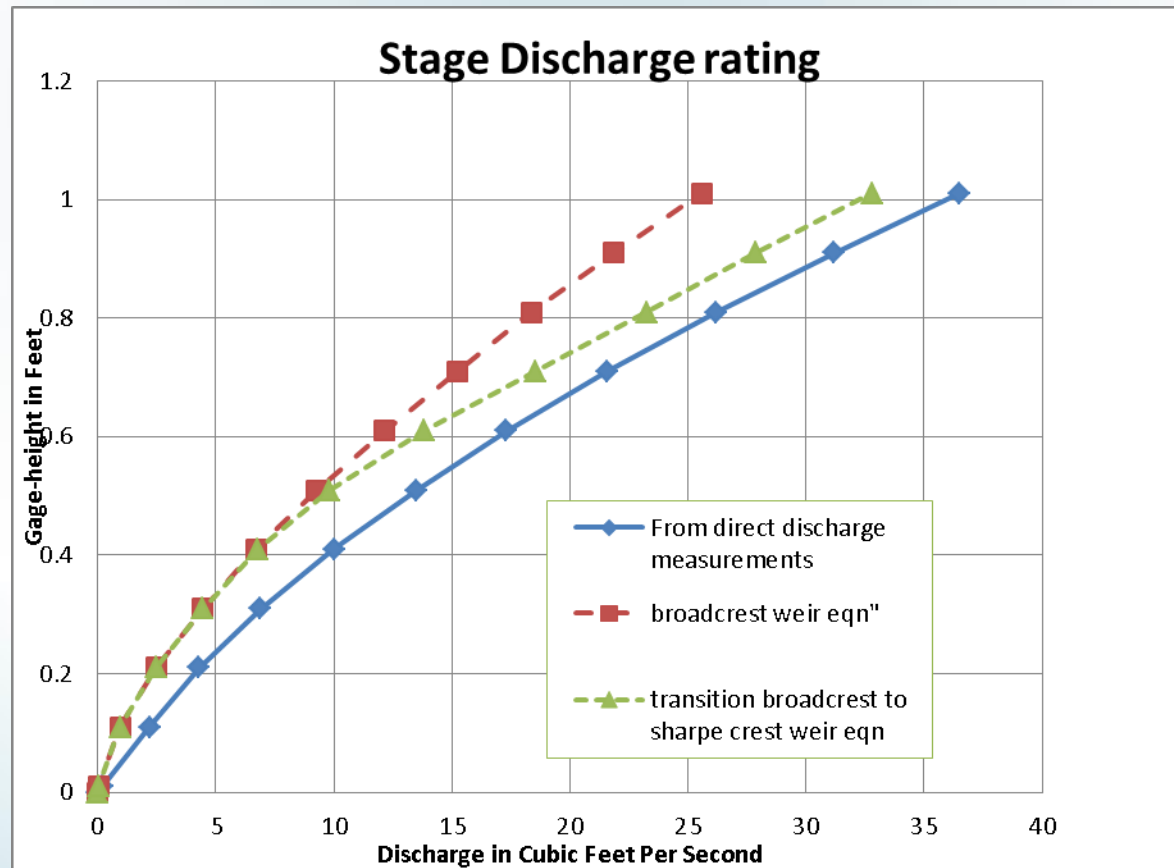
Example of a rectangular concrete weir

The weir has a thickness of 1 ft so it acts as a broad-crested weir at low to middle stages and as a sharp-crested weir at high stages according to weir theory.

A comparison of stage-discharge ratings developed using

- broad-crested-weir equation
- weir equations transitioning between broad- and sharp-crested weir, and direct discharge measurements is shown (next slide)

Comparison of stage-discharge ratings developed from weir equations and direct measurements of discharge



Measuring flow in a flume

Discharge Equations for Selected Flumes



Parshall
 $Q = KH^n$



H-flume
 $Q = CH^{2.31}$



Montana
(short Parshall)
 $Q = KH^n$

Q, discharge; C and K, constant depending on size and design; H, head at reference gage; n, constant power dependent on throat width

Development of Stage-Discharge Rating Equation using Microsoft Excel

Example

This example uses discharges measured at a range of gage-heights. The goal is to develop a stage-discharge equation that can be used to convert recorded gage-heights to discharge in million gallons per day

<u>Gage height (ft)</u>	<u>Discharge (ft³/s)</u>	<u>Comments</u>
6.99	0.0	GZF
7.00	0.1	
7.11	2.3	
7.32	7.5	
7.37	8.7	
7.57	16.4	
7.61	18.0	
7.67	19.9	
7.77	24.1	
7.99	38.3	

GZF = gage-height at zero flow

Example

Step 1: Set-up Excel spreadsheet.

rating curve example.xlsx - Microsoft Excel

File Home Insert Page Layout Formulas Data Review View

Clipboard Font Alignment Number

D13 fx MGD = 0.646317 x ft³/s

	A	B	C	D	E	F
1						
2						
3	Gage-height (ft)	Gage-height at zero flow	Gage-height - GH zero flow	Discharge (ft ³ /s)	Discharge (MGD)	Comment
4	7.00	6.99	0.01	0.1	0.06	
5	7.11	6.99	0.12	2.3	1.49	
6	7.32	6.99	0.33	7.5	4.8	
7	7.37	6.99	0.38	8.7	5.6	
8	7.57	6.99	0.58	16.4	10.6	
9	7.61	6.99	0.62	18.0	11.6	
10	7.67	6.99	0.68	19.9	12.9	
11	7.77	6.99	0.78	24.1	15.6	
12	7.99	6.99	1.00	38.3	24.8	
13				MGD = 0.646317 x ft ³ /s		

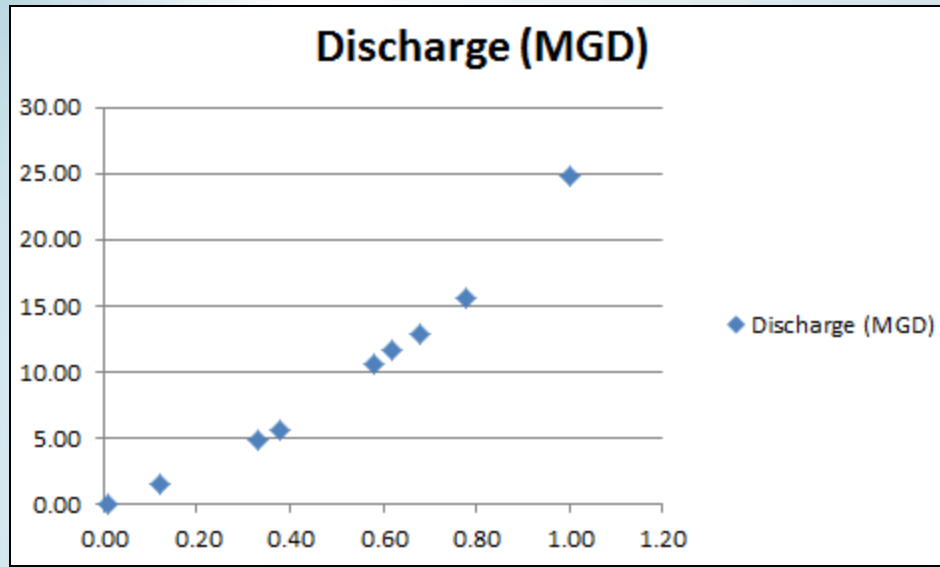
Example

Step 2: Select columns C and E and create a scatter plot.

rating curve example.xlsx - Microsoft Excel

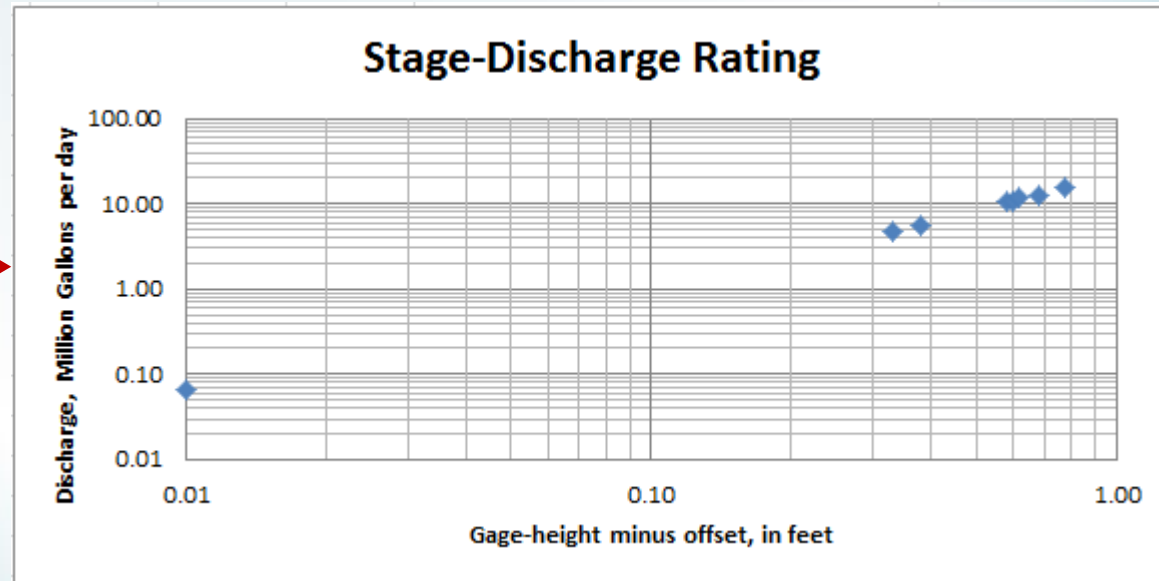
D13 fx MGD = 0.646317 x ft ³ /s						
	A	B	C	D	E	F
1						
2						
3	Gage-height (ft)	Gage-height at zero flow	Gage-height - GH zero flow	Discharge (ft ³ /s)	Discharge (MGD)	Comment
4	7.00	6.99	0.01	0.1	0.06	
5	7.11	6.99	0.12	2.3	1.49	
6	7.32	6.99	0.33	7.5	4.8	
7	7.37	6.99	0.38	8.7	5.6	
8	7.57	6.99	0.58	16.4	10.6	
9	7.61	6.99	0.62	18.0	11.6	
10	7.67	6.99	0.68	19.9	12.9	
11	7.77	6.99	0.78	24.1	15.6	
12	7.99	6.99	1.00	38.3	24.8	
13				MGD = 0.646317 x ft ³ /s		

Example



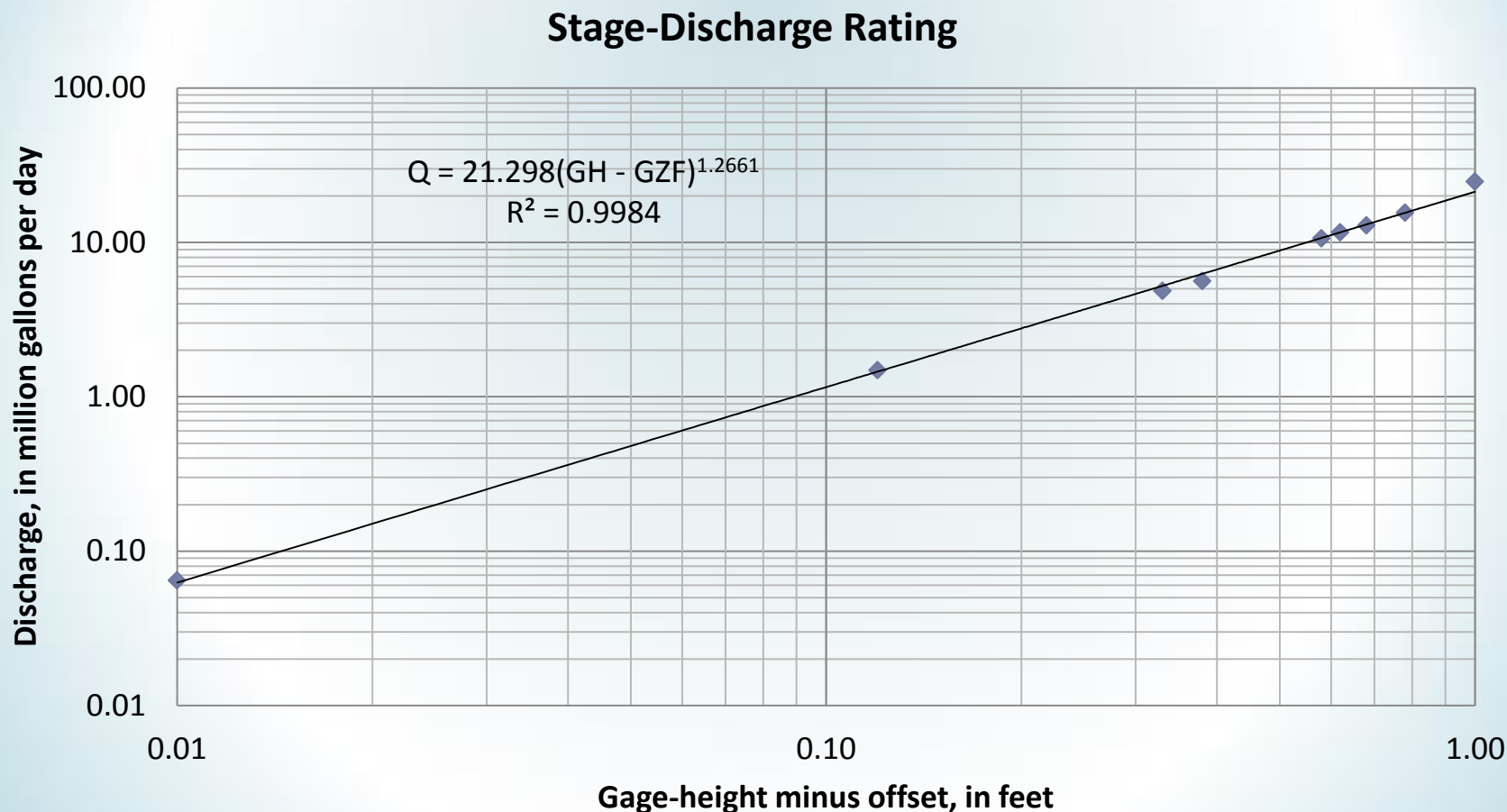
Step 3: Change scatterplot axis to log scale.

Step 4: Convert to log-log scale, add major and minor axes, label axes and chart title.



Example

Step 5: Add trendline (select power regression with equation and R²).



Excel will show the equation as $y=21.298x^{1.2661}$.
Change y to Q and x to GH-GZF.

Example

Step 6: The resulting equation for the trendline will be used to convert recorded gage-heights to discharge.

